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The effects of impact loads from match play and training on performance measures within rugby union

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The effects of impact loads from match play and training on performance measures within rugby union

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Abstract

Rugby union is a full contact sport comprising of impact or collision elements. There has been a propensity to research more locomotive aspects of the game in terms of distances covered, velocity and high intensity efforts. However, with the potential exception of biochemical markers resulting from muscle damage, little has been investigated from the aspect of impacts effecting performance measures. Therefore, the purpose of this study was to i) identify relationships between impact loads and changes in peak power (PP) as a result of match play and training loads from global positioning system (GPS) technology (Catapult Innovations, Melbourne, Australia); and ii) investigate the response of PP to recovery periods as markers of neuromuscular fatigue (NF) within rugby union. Twenty nine elite male rugby union players, age 26.3 ± 3.9 years, height 185.2 ± 7.9 cm, and mass 101.7 ± 13.1 kg participated in the study. Participants performed three loaded (20kg Olympic bar) countermovement jumps (CMJ) at a self-selected depth on a portable force platform on the first training day (wkstart or post-match), and last training day (wkend or pre-match) of each competitive week over twelve weeks. All training and match play impact loads were recorded using GPS accelerometry and correlated with peak power differences as a result three or four day training periods or recovery periods of 48hrs and 72hrs. Significant ($p < 0.05$) negative correlations between zone 2, 3 and 5 impacts were recorded with zone 5 being the strongest during a three day training week alongside non-significant ($p = 0.553$) and trivial (effect size; ES = 0.14) changes in PP output. No significant correlations existed between the four day training week impacts and PP output, however there was a significant ($p = 0.01$) moderate (ES = 0.67) increase between week start (4609 ± 1081w) and week end (5192 ± 605w) PP values. There were no significant correlations between zoned impacts and PP following 48hrs or 72hrs of post-match recovery. Only total impact numbers from a three day training week were found to have a significant ($p = 0.018$) weak effect upon PP difference. At 48hrs post-match there was a significant ($p = 0.004$) but also moderate (ES = 0.61) negative reduction from pre-match (5122 ± 915w) and 48hrs post-match (4517 ± 1064w) recovery values. No statistical difference ($p = 0.733$) between pre-match (5275 ± 792w) and 72hrs post-match (5202 ± 726w) peak power was identified yet there was a significant decrement ($P = 0.009$) and interaction ($p = 0.038$) between post-match 48hrs and 72hrs peak power values. The monitoring of impact loads from either the three and four week training week, or as a result of 48hrs and 72hrs post-match recovery did not provide conclusive evidence that impacts, zoned or total, directly affected PP. It was however identified, predominantly through match play that recovery duration has a significant effect upon recovery itself, whereby a shorter period of recovery results in a greater performance deficit through the use of PP. Future recommendations are the use of positional data, as opposed to group data, in order to acquire a more finite perspective on the effects of impacts on PP within positional groups. Further, an extended time period of investigation would allow greater detail with regard to the affect upon recovery and training strategies within a competitive season of accumulated impacts and varying recovery periods.

List of Abbreviations

Analysis of Variance	ANOVA	Maximal Voluntray Contraction	MVC
Adenosine DiPhosphate	ADP	Metres Per Minute	$m \cdot min^{-1}$
Adenosine Triphosphate	ATP	Minutes	mins
Central Nervous System	CNS	Multiple Countermovement Jump	CMJ5
Change of Direction	COD	Neuromuscular Fatigue	NF
Countermovement Jump	CMJ	Peak Force	PF
Creatine Kinase	CK	Peak Height	PH
Creatine Kinase Concentration	[CK]	Peak Power	PP
Delayed Onset of Muscle Soreness	DOMS	Peak Power Output	PPO
Global Positioning System	GPS	Peak Rate of Force Development	PRFD
Gravitational Force (g-force)	g	Range of Motion	ROM
Ground Reaction Forces	GRF	Single Countermovement Jump	CMJ1
Hours	hrs	Squat Jump	SJ
Kilogram	kg	Stretch Shortening Cycle	SSC
Kilometre	km	Velocity Max	Vmax
Kilometres Per Hour	$km \cdot h^{-1}$		

1.0 Introduction

Rugby Union is a sport recognised by characteristics of repeat high intensity workloads comprising of high velocity movements, accelerations and decelerations interspersed within periods of walking, jogging and running (Cahill et al. 2013, Duthie, Pyne and Hooper 2005). Additionally and in combination with these facets are impact and collision loads, which are accumulated within the competitive environment but also the training week throughout the season (Smart et al. 2008, Takarada 2003, Young, Hepner and Robbins 2012). Regular exposure of players to external physical force through aspects such as tackling, rucking, and mauling, alongside the generation of high eccentric loads and multiple stretch shortening cycle (SSC) activities induces a high proportion of physical and metabolic stress upon the players and exposes them to fatigue (Ehlers, Ball and Liston 2002, Marques et al. 2008, West et al. 2014).

Rugby union comprises 15 specific positions within a squad, all with their own physical characteristics based around strength power and speed, alongside skill sets or tasks within their role (Duthie, Pyne and Hooper 2003). Positions are commonly split into two positional groups of forwards (positions 1-8) and backs (positions 9-15). The forwards are typically larger than backs dealing predominantly with close-quarter work covering on average 5.9 km per game. The backs however are exposed to more open play at 6.5 km per game through greater velocity efforts, with average maximums of 30.4 $km \cdot h^{-1}$ in comparison to the forwards 26.3 $km \cdot h^{-1}$ (Cahill et al. 2013). Due to their role forwards are exposed to more static events involving impacts or collisions at 89 ± 21 events in comparison to 24 ± 10 (Roberts et al. 2008), in addition forwards are uniquely involved in scrummaging occurring as many as 29 times per game (Eaton and George 2006, Lacome et al. 2014, Quarrie et al. 2013).

The competitive season in the northern hemisphere begins in September and ends in May, during which time the majority of squads can expect to compete each week. Therefore, throughout this period the understanding from coaching and support staff of the aforementioned components is of importance. This is especially the case in relation towards effective post-match recovery strategies in particular from neuromuscular fatigue (NF) and training regime development, whereby players are not over trained or further exposed to injury risks, and are returned to optimal performance levels prior to competition on a weekly basis (Cahill et al. 2013, Duthie, Pyne and Hooper 2005, Gabbett 2010, West et al. 2014).

Previously video or notational analysis has been regularly used to quantify the demands of the game from a locomotion aspect, in order to effect changes to training loads or stimulus (Cunniffe et al. 2010, Smart et al. 2008, Takarada 2003). However, this approach relies upon subjectivity whilst providing almost a superficial insight. The introduction of global positioning systems (GPS) has provided opportunity for greater range and depth of measures, in comparison to time motion analysis of the positional and physical demands of match play, particularly towards distances covered, velocity thresholds, and accelerations and decelerations (Cahill et al. 2013, Gabbett, Jenkins and Abernethy 2012b, Young, Hepner and Robbins 2012). Whereas these measurements have relevance in relation to training loads and recovery they are limited in providing finite or three dimensional detail pertaining to magnitudes of multidirectional forces and the subsequent effects upon players that GPS accelerometry could provide. External loads, for instance from ground reaction forces (GRF) or forces from change of direction (COD), have to be considered, yet more specifically, within a contact sport there are events of blunt force trauma or impact to consider. These are known to cause muscle structural damage resulting in NF, therefore understanding the implication of repeat exposure and the accumulation of impacts has relevance in relation to recovery and repeat performance (Fuller et al. 2007a, Quarrie and Hopkins 2008).

Although not directly addressed within this study, bio-markers have been effectively utilised in quantifying the effects of impact and collision loads resulting in muscle structural damage, therefore provide a point of reference in terms of infrastructural loss within contact sport. One of such measures is creatine kinase (CK), an enzyme located within the sarcolemma and mitochondrial intermembrane space, which can be released mechanically into the blood as a direct result of impacts. McLellan, Lovell and Gass (2011), Smart et al. (2008), Takarada (2003), and Young, Hepner and Robbins (2012) all detail links to physical contacts and external loads exceeding the integrity limits of muscle structures and function resulting in the subsequent release of CK with peak concentrations occurring anything up to 24hrs to 48hrs post-match. Both Smart et al. (2008), and Takarada (2003) within rugby union identify significant position specific pre- to post-match increases in CK correlated to the number of impacts that players are exposed to. Young, Hepner and Robbins (2012) within Australian Rules football also find significant increases in CK as a result of increased exposure to multi-planar impacts. Performance markers have also been incorporated into the monitoring of fatigue in conjunction with bio-markers. McLellan, Lovell and Gass (2011) relate decrements of peak power (PP), and peak rate of force development (PRFD) values within rugby league to peak values of CK up to 48hrs post-match. Similar has been observed within elite male soccer where at 48hrs, 20m sprint times were at their greatest decline whilst CK peaked at this time point (Ispirlidis et al. 2008).

In relation to recovery processes, an understanding of the concomitant relationships of performance and bio-markers to the time frames to which fluctuations of recovery occur, provides scope towards an effective indicator of NF. Performance measures have been found to follow a bimodal trend resulting in an initial acute decline in performance, a period of recovery, followed by a secondary decline at which point there is often a concomitant increase or peak in CK (Avela et al. 1999, Faulkner, Brooks and Opiteck 1993). The mechanisms responsible for this are related to reductions in joint stiffness and stretch reflex capabilities (Komi 2000, Nicol et al. 1996, Toumi et al. 2006). This in part holds relevance to NF whereby there is a loss of voluntary muscular activation thus having a detrimental effect upon any type of explosive movement pattern which incorporates the stretch shortening cycle (SSC; Enoka 2008, Gandevia 2001). Therefore, the selection of performance measure and the mechanism through which it is tested is critical. One such measure is PP which has a high level of reliability in relation to NF, but also has relevance to high intensity activity in that movement velocity depends upon power production alongside elements of play such as sprinting, jumping and change of direction (Batterham and Hopkins 2006, Fowles 2006, Hopkins, Schabort and Hawley 2001, Ross, Leveritt and Riek 2001, West et al. 2014). If in conjunction with a relevant mode of measure such as the countermovement jump (CMJ) which incorporates the SSC, thus relevant to the bimodal trend, power becomes a specific performance measure that is sensitive to NF (Bishop 2012, Fowles 2006), whilst due to its reliance upon muscle structural integrity will also be affected by accumulated impact and collision loads.

Thus with significant relationships existing between time frames of recovery as a result of impact loads and sensitivity of PP to NF, there is potential in the combination of a direct measure of impact loads from GPS and power values. This then could highlight the effects of impacts upon NF and have relevance towards training load prescription, recovery processes and game preparation. Therefore the aim of the present study was to i) identify relationships between impact loads and changes in PP as a result of match play and training loads from GPS technology; and ii) investigate the response of PP to recovery periods as an indicator of neuromuscular fatigue within rugby union. It was hypothesised that the accumulation and magnitude of impact loads will result in greater decrements in PP output. Further, the duration of recovery or training week will allow for a greater return to pre-training or pre-match PP values.

2.0 Literature review

2.1 Locomotion:

The locomotive aspect of team sports in particular both codes of rugby, soccer and Australian rules football has often been researched (Austin, Gabbett and Jenkins 2011, Bloomfield, Polman and O'Donoghue 2007, Cunniffe et al. 2009, Gabbett, Jenkins and Abernethy 2012b, McLellan and Lovell 2013, Quarrie et al. 2013, Roberts et al. 2008, Young, Hepner and Robbins 2012). The dominant study corresponding to rugby union in the northern hemisphere was initiated by the Rugby Football Union and utilises data from eight premiership rugby union clubs throughout the 2010/2011 season (Cahill et al. 2013). This was the first study of its kind in England to record datasets solely through the use of GPS technology and its in-built accelerometers and magnetometers. During competitive match play the forwards were found to cover on average 5.9 km a distance significantly less in comparison to backs at 6.5 km.

Although useful, the distances covered in isolation have little meaning, yet in its earlier stages of use in applied environments this variables was relied upon for training load prescription but also limitation. Whereas the distance itself does hold value it is the components of those distances in terms of intensity with relation to velocities, metres per minute ($m \cdot min^{-1}$), acceleration and deceleration that allows greater understanding of the external loads applied to a player, which can then be used in conjunction with metabolic or internal loads and subsequent efficiencies of game play or training for training and recovery purposes. In terms of velocity of movement a forwards average maximum is 26.3 $km \cdot h^{-1}$ and a backs 30.4 $km \cdot h^{-1}$. However, overall rugby union is played at low velocities with the forwards and backs averaging only 5.4 $km \cdot h^{-1}$ and 5.5 $km \cdot h^{-1}$, with median and inter-quartile ranges indicating 37 ± 64m and 50 ± 76m of overall metres covered at greater sprinting speeds (81-95% max velocity; Vmax), respectively. Forwards covered greater distances 2.6 km and produced the greatest percentage of play (46.2%) at 20-50% Vmax whilst the backs were greatest at <20% Vmax averaging 3.0 km but covered more distance sprinting (81-95% Vmax) than the forwards by 37%. Therefore metres per minute values ($m \cdot min^{-1}$), which is a distance marker relative to playing time, highlights the intensity of work throughout the positions and has potential as a marker of intensity and performance during match play and training, but also a scale to work from in terms of stimulus prescription when applying match data to training loads. Values of 64.6 $m \cdot min^{-1}$ and 71.1 $m \cdot min^{-1}$ respectively are both significantly different between the playing groups yet further difference between individual positional groups exist and once again training stimulus should take this into account (Cahill et al. 2013).

The differentiation between positions is to be expected due to more close quarter engagement of the forwards with the opposition and lower velocity plays in comparison to more open running involvement with less physical contact for the backs (Duthie, Pyne and Hooper 2003). However, whereas these data in isolation provide detail that can be utilised in the preparation of future training sessions by coaching staff it is the contrasts in physicality and locomotion that highlight a need for greater detail from a mechanical perspective especially in terms of recovery strategies, training loads and availability to train (Quarrie et al. 2013). Jumping forces, GRF, change of direction (COD), and blunt force trauma from impact or collisions through multiple planes or axes of motion have a deleterious effect on performance but also potentially the levels of fatigue induced upon the player (Brughelli, Cronin and Chaouachi 2011, Deutsch, Kearney and Rehrer 2007, Grabowski and Kram 2008, McLellan and Lovell 2012, Sykes et al. 2011, Twist et al. 2012).

Grabowski and Kram (2008), and Brughelli, Cronin and Chaouachi (2011) suggest that at running velocities of 40% - 60% Vmax the vertical forces are at their greatest, but remain constant from that point. At velocities >40% Vmax through to 100% Vmax the horizontal forces generated significantly increased with a 102% difference between them, which was 11% greater than the vertical forces at Vmax. Therefore each playing position has the potential to generate differing forces in terms of GRF's that need to be considered. Another aspect is the increase in GRF through acceleration (propulsive), and deceleration (breaking), forces as running velocities alter. These observations support the findings of Kyrolainen, Avela and Komi (2005), whereby it is identified through EMG studies in elite middle distance runners, that pre-activity of the muscle exceeds maximal voluntary contraction (MVC) capabilities of human muscles as a preparatory mechanism for deceleration or the braking phase of high speed running mechanics. These forces are significantly greater than that of the propulsion phase of running of which only generated 50% MVC. The deceleration forces at greater velocities also increase eccentric loading which is linked with muscle tissue damage as identified by Young, Hepner and Robbins (2012) through Australian Rules football. In this instance those that accrued greater instances of sprinting over greater distances, thus being exposed to greater acceleration and deceleration forces, showed signs of greater muscle tissue damage because of the high intensity muscle actions but also GRF.

As a consequence of these findings there is suggestion that basic understandings of distances are useful, but there are underlying implications in terms of stimulus exposure for adaptation and injury prevention that must be addressed. Much of the data now generated within applied environments is from GPS technology with more team or field sports utilising it (Boyd, Ball and Aughey 2011, Gabbett, Jenkins and Abernethy 2012b, Gabbett, Jenkins and Abernethy 2010, Jennings et al. 2010, McLellan and Lovell 2013). Little research exists though on these components of locomotion and the mechanical demands of particular sports in particular towards impact and collision loads which are not only as a direct result of blunt force trauma but also the aforementioned forces generated during performance. This notion is supported by Aughey (2011) in saying that the integration of technology and the data it produces will only expand our knowledge of the demands of competition and training.

2.2 Muscle Structure Integrity Loss:

Much is written and understood about the loss of structural integrity from a physical performance perspective in both controlled and applied professional environments. Aspects such as strenuous exercise and high levels of eccentric loading, often invoked through the SSC (Dousset et al. 2007, Hody et al. 2013, Kamandulis et al. 2010, Lovering and De Deyne 2004, Marqueste et al. 2008, Nicol and Avela 2006, Nicol and Avela 2006, Semmler 2014), high impact collision (Elmer et al. 2012, McLellan, Lovell and Gass 2011, McLellan and Lovell 2012, Takarada 2003), cumulative distance and the combative nature of team sports are all common factors of comparison within research of rugby union (Cunniffe et al. 2010, Ehlers, Ball and Liston 2002, Mclellan, Lovell and Gass 2011).

Eccentric loading is a popular facet which has been suggested to cause the most amount of muscle structure damage with decrements in performance lasting between 24hrs to 192hrs post eccentric activity (Ehlers, Ball and Liston 2002, Eston, Mickleborough and Baltzopoulos 1995, Marqueste et al. 2008, Nicol and Avela 2006, Semmler 2014). Team sports such as rugby union are synonymous with regular accelerations and decelerations, multidirectional movement patterns alongside jumping type activities which utilise the SSC, thus generate eccentric loads and lead to these decrements in performance measures. Such changes are based around the principle of neuromuscular function and contractile ability loss as a direct result of the lengthening of muscle fibres which damages the sarcoplasmic reticulum but also the sarcomere itself, therefore decreasing the effect of actin and myosin filaments (Eston, Mickleborough and Baltzopoulos 1995, Lovering and De Deyne 2004, Nicol and Avela 2006, Semmler 2014). Structural damage reduces the force production capabilities of the muscle, whilst the transmitting structure damage would alter the pathways of afferent signals going to the central nervous system (CNS) thus affecting the size and number of muscle actions and subsequently limit adenosine triphosphate (ATP) generation through lack of stimulus (Enoka 2008, Gandevia 2001).

Baird et al. (2012), Kamandulis et al. (2010) and Newton et al. (2008) all make reference to the ability to adapt to eccentric loading through training and exposure to this type of loading, resulting in the decrease of CK markers between trained and un-trained individuals. Whereas this may be the case it may not be true of blunt force trauma as the damage is from external influences, therefore the recording of contacts is still of relevance. Therefore, from the perspective of impacts or collisions there is a need for the quantification of the physical demands through player impacts, and there is indeed much to be said in terms of muscle structure viability within collision sports (Duthie, Pyne and Hooper 2005). Fuller (2007a, 2007b) categorise aspects of the game to Collision, Lineout, Maul (collapsed and not collapsed) Ruck, Scrum (collapsed and not collapsed) and tackles, to which all involve impacts and have a propensity to illicit injury. From the 2003/04 and 2005/06 English premiership rugby seasons, tackles, the most common contact event, were responsible for the highest number of injuries and the greatest time loss from competition or training. Collisions (an attempt to stop the ball-carrier without the use of the arms) were 70% more likely to inflict injury than a tackle whilst scrums had a 60% greater likelihood. This data has importance and although the focus is upon time-loss injury it highlights the intensity of the game from the perspective of blunt force trauma.

Quarrie and Hopkins (2008) alter their definitions of injury, particularly around the event taking the ball-carrier to ground, but ultimately identify similar characteristics to Fuller (2007a, 2007b). Fuller et al. (2007a) refer to injury or physical complaint as being due to the transfer of energy exceeding a bodily structures ability to maintain its structural or functional integrity. This is not to say that every exogenous contact or trauma is likely to result in injury, but is one facet of the game liable to cause structural tissue damage as eluded to within impact and collision research in both training and match play by Gabbett, Jenkins and Abernethy (2010) and Gabbett, Jenkins and Abernethy (2011). Indeed, such damage can manifest itself as delayed onset muscle soreness (DOMS) (Ispirlidis et al. 2008, Kanda et al. 2013), a loss of force production (Byrne and Eston 2002), and decrements in range of motion (ROM), and is synonymous with the release of muscle proteins such as myoglobin, myosin heavy chains and CK (Magal et al. 2010, Tee, Bosch and Lambert 2007). Located within the sarcolemma and mitochondrial intermembrane space CK is the primary enzyme (Baird et al. 2012, Ehlers, Ball and Liston 2002), and is responsible for catalysing the reversible exchange of phosphate bonds between phosphocreatine and adenosine diphosphate (ADP) to ATP (Brancaccio, Maffulli and Limongelli 2007, Ehlers, Ball and Liston 2002, Magal et al. 2010). It can be released into the blood metabolically, whereby a decrease in muscle fibre membrane resistance occurs as a result of ATP depletion, and the subsequent change in intracellular calcium homeostasis, or mechanically through sarcomeric degeneration from Z-disk disruption, which is more prevalent in Type II muscle fibres (Baird et al. 2012, Brancaccio, Maffulli and Limongelli 2007, Duncan 1987, Tee, Bosch and Lambert 2007). The metabolic release has relevance, but it is the mechanical cause of the release of CK that holds importance to this study. Although not directly measured in this instance, as suggested by Twist and Highton (2013), it provides a basis for understanding, and a point of reference as to the effects of impacts within an applied environment. Its release is a direct consequence of muscle fibre damage resulting in a reduction of cross bridge attachment, but also increased intramuscular pressure leading to an eventual loss of force production, which is concomitantly identifiable through reductions in performance indicator values (Cunniffe et al. 2010, Elmer et al. 2012, Smart et al. 2008, Takarada 2003).

Smart et al. (2008) investigated pre- to post-match (within 30mins) changes in interstitial CK concentrations, and its relationship with impacts from tackles amongst elite level players over five competitive matches. In this instance position-specific increases of CK were found, whereby there was a significantly greater increase in CK amongst the forwards compared to backs, with the number of impacts and collisions per minute also being significantly greater. This is to be expected due to the increased contact load for the forwards through scrums, rucks, mauls and tackling (Cahill et al. 2013, Quarrie et al. 2013) whilst less of an increase in CK in backs will be due to less impacts, but also because they engage in more of a running style of play with potential behind an element of recovery in low intensity jogging and subsequent clearance and re-uptake of CK (Cunniffe et al. 2010, Gill, Beaven and Cook 2006). This is similar in design to an earlier study by Takarada (2003) who conducted a two match study of amateur rugby union players whereby plasma CK samples were taken prior to and post-match, but also at extended intervals of 24hrs, 48hrs and 72hrs, whilst video analysis quantified the number of tackles. At 24hrs post-match there was a significant increase in CK with a concomitant significant correlation between tackles and mean CK values which peaked at this point before returning to pre-match (48hrs) values within 72hrs. It is suggested by Smart et al. (2008) that a flaw in the earlier study is that only events whereby players were tackled or tackling from the front were used thus omitting any other form of collision which is important. However, Smart et al. (2008) do not continue their measurement of CK for a prolonged time, which is the case of Takarada (2003) showing clearly that levels of CK may increase slightly for up to 90mins post-match but it is durations of up to 24hrs or greater that might have more importance in terms of recovery. But in both cases it could be said that the use of video or notational analysis for grading collisions may not be consistent or effective enough in terms of grading the magnitude of contact, which has relevance in terms of kinetic energy transfer from tackling or being tackled and its subsequent effect upon muscle infrastructure. Of interest in both these cases is highlighted by Smart et al. (2008) when referring to differences in CK immediately post-match in comparison to Takarada (2003) could be as a result of differences in style of play and anthropometric variation between Japanese and New Zealand rugby players.

The time courses of CK variance throughout research remains quite consistent. In the instance of Cunniffe et al. (2010), examining international rugby union players over one match, they were able to identify significantly increased and peak CK at 14hrs post-match with a continued but lesser significant pre- to post-match comparative increase at 38hrs, although even at this later stage values were 2.3 times the levels of that at the pre-match stage. Cunniffe et al. (2010) refers to sports such as American football and soccer (Hoffman et al. 2002, Hoffman et al. 2005, Ispirlidis et al. 2008), in that their athletes have lower resting CK levels in comparison to rugby union potentially through greater clearance rates and a decreased loss of membrane integrity. However, as per their results of significant correlations between contact and tackle events at both 14hrs and 38hrs the more likely reason is that of greater physical trauma.

Young, Hepner and Robbins (2012) introduce GPS measures, whereby CK values are correlated to in-game markers of distances covered, distance at velocity and accelerations and decelerations. From this it was found within elite junior Australian rules footballers, those who generated greater total distances, particularly at higher velocities (6.0 – 7.0 $m.s^{-1}$), and produced more high level accelerations (3 – 15 $m.s^{-2}$), and decelerations (-3 – -15 $m.s^{-2}$), accrued a greater level of muscle damage in comparison to those with lesser volumes of work, through pre- to post-match CK comparisons at 24hrs post-match. Whilst, investigations such as Ispirlidis et al. (2008) highlight that there are other indirect indices at similar time courses within sport that have correlations to CK levels. Ispirlidis et al. (2008) found that within a group of elite male soccer players, over a six day recovery period, CK values were at their greatest and most significant at 48hrs post-match, alongside the slowest 20m sprint time, greatest delayed onset of muscle soreness (DOMS) score, and least knee joint range of motion; the majority of which including CK did not reach peak recovery values until 120hrs. Howatson and Milak (2009) followed the course of CK fluctuations through sports specific repeated efforts of fifteen single 30m sprints with a sixty second rest interval in order to review exercise induced muscular damage. Knee extensor isometric MVC were significantly decreased, and at their lowest, at 24hrs post-exercise with a return to pre-exercise non-significant values at 72hrs post-exercise with a similar effect for mid-thigh limb girth measurements. At 24hrs CK were at their peak and remained significantly increased until 72hrs, whilst muscle soreness measures were at their peak significant values at 48hrs post exercise, but maintained increased values until 72hrs post-exercise. In this instance, of interest is the peak at 24hrs of MVC which corroborates finding by Andersson et al. (2008), Cormack, Newton and McGuigan (2008) and Mclellan, Lovell and Gass (2011), whereby voluntary muscular actions return to baseline or pre-exercise measures at a faster rate than CK values and increased muscle soreness scores. All mention the more peripheral effect of fatigue having this short term effect upon markers such as MVC, whilst in addition Duffield et al. (2012) suggests that in studies where the participants are at more of an amateur level, the return of MVC levels may be delayed due to decreased adaptation to the demands of a match over international or elite level performers, for which values return to baseline measures at a more rapid rate. Therefore, the continued delayed return to baseline CK values is an indication of the remaining muscle infrastructural damage, and markers of more neural aspects of performance over values of force generation could have greater ability in relation to infrastructural loss as a result of impact loads.

2.3 Impact Loads:

Roberts et al. (2008) suggested at the time that motion analysis, was one of the most effective means of quantifying activity within rugby union. Typically data is presented as mode, frequency and overall duration of differing activities and in terms of distances covered this may be accurate enough (Austin, Gabbett and Jenkins 2011, Lacome et al. 2014, Quarrie et al. 2013, Roberts et al. 2008). However, as previously mentioned with the example of Takarada (2003) and Smart et al. (2008), there has also been a reliance upon video or notational analysis, which is a subjective method of grading, and as with both of these examples only takes into account physical contact between two players. Thus, this type of analysis is potentially inaccurate in terms of measuring exogenous forces upon the body, forces of which will have differing effects on muscle structural integrity depending on the anthropometric characteristics of the individual (Duffield et al. 2012, Quarrie et al. 2013, Smart et al. 2008, Takarada 2003). Furthermore the connotations of movement variables prior to impact, and the direction and height of the impact upon the body, all hold bearing on the physical outcome and potential of muscle infrastructural damage, but also the development of training strategies to expose players to impact stimulus (Gabbett, Jenkins and Abernethy 2011, Gabbett, Jenkins and Abernethy 2012a, Quarrie and Hopkins 2008, Quarrie et al. 2013, van Rooyen, Yasin and Viljoen 2014).

Thus far it has been established that a fundamental factor of rugby union is that of the Impact or collision. Indeed the predominant method of gaining possession of the ball, or disrupting play of an attacking opposition involves tackling. The number of tackle events per squad are consistent per match with Fuller (2007a) reporting an average of 221, Quarrie and Hopkins (2008), 203 ± 29, and 200 by van Rooyen, Yasin and Viljoen (2014). However, at 14.8 events per match, Fuller (2007a) suggests that collisions, where contact is made without the use of the arms, are 70% more likely to cause injury than a tackle itself. However these figures provide no indication as to the effects they have upon the individual and it is not always possible to detect the magnitude of, or grade each impact. As an example, supported by the use of Catapult GPS, Gabbett, Jenkins and Abernethy's (2010), grade the intensity of a tackle event based on video analysis of play, as mild (equivalent of zone 1-2; See **Table 1**), where a player is tackled but able to continue motion out of the tackle itself, moderate contact (zone 3-4; See **Table 1**), whereby forward motion or momentum continues until the tackle is completed, or heavy (> zone 4; See **Table 1**), resulting in the players forward motion being halted and forced backwards in the tackle. Despite having a description of tackle types such as this by Gabbett, Jenkins and Abernethy's (2010), it still remains difficult to conceptualise what constitutes an impact, and it is this type of detail amongst research of impacts using micro technology, such as GPS units with inbuilt accelerometers, that is lacking in current bodies of research (Cummins et al. 2013).

In terms of the measure of impact loads, few have looked in any detail towards the use of GPS and accelerometry, which allows a three dimensional in game or training perspective, in particular around impacts. Young, Hepner and Robbins (2012) utilise a "player load" marker, specific to the GPS manufacturer (Catapult Innovations), which measures the combined three dimensional acceleration and decelerations measurements from accelerometry, taking into account non-locomotive factors such as jumping, impacts, tackles and collisions. Essentially this is a marker of mechanical load and it was found that those with greater CK values, amongst junior level Australian rules, also had a 42% greater player load value in comparison, yet this gives no orientation to the magnitude of load. McLellan and Lovell (2012), do however use GPS accelerometry to record the magnitude of collisions and by following elite level rugby league matches were able to identify a significant rise in CK at 24hrs, 48hrs and 72hrs post-match. More crucially at this point, significant correlations between CK and collisions recorded at the second highest (8.1-10g) and highest (>10g) g-force range of impact were identified for the GPS units. Suárez-Arrones et al. (2012), in elite rugby union, utilise a similar GPS unit to Mclellan and Lovell and Gass (2012) (Team AMS; GPSports), but detail very little other than over a three match period the forwards received 32% more impacts than the backs, with significance only between moderate-heavy, and heavy impact loads but make no relation to any other performance measure. Venter, Opperman and Opperman (2011) in under

19 rugby union match play, and also Gabbett, Jenkins and Abernethy (2012b), in professional rugby league make reference to differences within positional groups and the severity of impacts, but make no correlations to performance measures, of for example PP. This is understandable within the context of the research, but overall the research has a theme whereby the understanding of impact loads is apparent and beneficial, but limited in terms of determining training loads and recovery due to substantial evidence of their effect upon indirect measures of fatigue or muscular structural loss.

Aside from the tackle, rugby union also involves more specific features include rucking, whereby players from both teams close around the ball that is on the ground, and mauling, where the player carrying the ball remains on their feet and binds to, or is bound upon by other players often as the result of intense physical contact (World Rugby 2015). These are considered as static events, which also require consideration in terms of further exposure to impact or mechanical loading. Although not stating specifically for which positional groups or types of static events, Lacome et al. (2014) identifies 53 such events occurring within a game, which is lower than that of 66.9 ± 15.8 for forwards and 9.5 ± 5.7 for the backs by Deutsch, Kearney and Rehrer (2007), 80 ± 17 and 21 ± 11 (Duthie, Pyne and Hooper 2005), 89 ± 21 and 24 ± 10 events from Roberts et al. (2008). The difference between forwards and backs is to be expected with the forwards being involved more in close quarter work. The disparity in events could also be anticipated due to differing styles and level of play of the teams studied, but potentially more specifically, as Lacome et al. (2014) suggests, the methodology adopted in terms of analysis in determining events could also be a factor. And it is the latter that potentially initiates a need for alternative methods of registering events which could go unnoticed.

Another source of impact and additional multi-planar force is that of the engagement during the scrum and a subsequent sustained pushing phase. In basic terms, the scrum is formed in the field of play when a maximum of eight players from each team bind together in three rows each (Front row, Second Row and Back Row). Under verbal control from the referee, players close in and bind with their opponents so that the heads of the front row players of both teams are interlocked. At this point the two teams engage together before applying coordinated pushing actions in order to compete for the ball (Trewartha et al. 2014, World Rugby 2015). The occurrence of scrums is consistent with Quarrie et al. (2013) stating approximately 25 per match, alongside frequency numbers of 22 by Lacome et al. (2014) and 29 ± 6 (Eaton and George 2006).

Scrummaging at the point of engagement and the sustained subsequent pressure has been investigated from a biomechanical loading point of view but also with regard to injury (Cazzola et al. 2015, Milburn 1990, Preatoni et al. 2015, Trewartha et al. 2015). This is of relevance in terms of the fact that although it is identified by Fuller et al. (2007a) that the scrum is 60% more likely to cause injury than tackling alone, the concern is from the mechanical loading as a result of each scrum that is likely to illicit muscle structural damage, thus impair performance (Preatoni et al. 2013, Preatoni et al. 2015, Trewartha et al. 2015). From more recent studies, Preatoni et al. (2013) identify peak engagement compression forces from an instrumented scrum machine at 16.5 ± 1.4 kN amongst international male and elite club level, with subsequent pushing forces of 8.3 ± 1.0 kN and 8.0 ± 0.70 kN respectively. Cazzalo et al. (2015) utilised pressure pads upon the shoulders of elite club front row players and recorded initial compression forces of 8.8 ± 2.2 kN with 3.8 ± 1.4 kN sustained push. Through earlier research Milburn (Milburn 1990), also using a scrum machine registered 7.9 kN at engagement of international male level players. These values do vary in magnitude, in-part this is down to the testing mechanism, whereby Cazzalo et al. (2015) used a contested scrum, therefore the testing itself was live, so the two opposing teams generate the speed on engagement, as opposed to an inanimate object. The variation could also be down to the changes in engagement process whereby they have been altered over time to limit the mechanical load players are exposed to (Cazzola et al. 2015, Preatoni et al. 2015, Trewartha et al. 2015). The concept of anthropometric differences of players, not just over time but amongst nationalities within a squad also hold bearing (Duffield et al. 2012, Quarrie et al. 2013, Smart et al. 2008, Takarada 2003). Milburn (1990) and Trewartha et al. (2015) indicate that the forward forces upon engagement were positively related to the combined momentum of the eight players going into contact, although no such correlation was found within the sustained pushing phase, of which has its own complications in terms of sheer and multi-planar forces. Therefore, technique, experience, anthropometric characteristics all affect the production of the forces upon engagement and sustained pushing within the scrum in order to compete for the ball. Therefore, the magnitude of the combined forces, which would vary amongst positional groups, but also as a result similar variations amongst the opposition, clearly cannot be predicted or identified in a simple fashion and to date there is no evidence to suggest that any GPS or accelerometry unit is capable of identifying the magnitude of the impact at engagement. Therefore, this study excludes observations derived from scrummaging.

Thus, it is clear that within contact sports mechanisms such as eccentric loading and blunt force trauma cause muscle tissue damage and that there is evidence of a delayed response in terms of recovery that is identified by returns to pre-match CK values ranging between 24hrs and 192hrs post-match. Therefore, providing an accurate measure of both performance, but also impact loading can be utilised with proven correlation to performance markers, such strategies within an applied environment can be enhanced. The use of GPS accelerometry has such potential, although there is little evidence and a dearth of data pertaining to its accuracy from an applied perspective. Instead, there is more of a reliance upon potentially flawed subjective video analysis, whereby collision or impact events are graded by an individual's perception instead of sensitive equipment, such as GPS. Research such as that by Mclellan Lovell and Gass (2011), and Young, Hepner and Robbins (2012) suggest such technology can generate impact measures accurately enough that subsequently correlate with indirect biochemical, or in this instance performance measures. However, it is the lack of detail towards the effects of impacts, of any form, on players that fundamentally forms the reasoning behind this study. Identifying a method of relating impact loads to a performance measure has the potential of allowing practitioners or coaches to react and allow more effective recovery strategies as a result of the exposure to impacts, but also allow players the exposure of collisions in order to condition them to the effects thus improve performance (Gabbett, Jenkins and Abernethy 2012a, Gabbett, Jenkins and Abernethy 2010).

2.4 Power and manifestations of fatigue in performance:

Power has been commonly used as an effective measure of both performance and fatigue (Fowles 2006, Hopkins, Schabort and Hawley 2001, Mclellan, Lovell and Gass 2011, Ross, Leveritt and Riek 2001, West et al. 2014). The product of force and velocity, it is reliant upon muscle recruitment, firing rates and synchronisation and intermuscular coordination (Cormie, McCuigan and Newton 2011, Ross, Leveritt and Riek 2001). Within team sports such as rugby union, American football, rugby league and Australian Rules football its generation is critical when they all rely upon multiple performance components of for example sprinting, jumping and COD where power provides the basis for velocity of movement (Cormie, McCuigan and Newton 2011, Marshall 2005, Newton and Kraemer 1994).

The fatigue perspective of power is a little more complex. Through peripheral fatigue the expectation would be a deterioration in performance due to the effects of metabolites, increased Pi concentrations or reduced pH and Creatine Phosphate concentrations (Ronglan, Raastad and Børgesen 2006). Whereas this does occur the result is not catastrophic to performance and in general relates to an inability to generate the required or anticipated force or power in order to maintain the required intensity through an alteration of the contractile mechanisms of the muscle

(Brooks, Fahey and Baldwin 2005, Edwards and Jones 1977, Kayser 2003, Shei and Mickleborough 2013). The central, more neurological model of fatigue is related predominantly to the involuntary reduction in voluntary muscular activation resulting in reduced maximal force production (Gandevia 2001, Kayser 2003, Ross, Leveritt and Riek 2001). Movements require the excitation of a muscle to produce force whilst shortening, which can be affected by reduced neural responses of afferent feedback loops through impaired neuromuscular transmission, motor unit recruitment and motor cortex activation (Elmer et al. 2012, Enoka 2008, Fowles 2006, Ross, Leveritt and Riek 2001, Shei and Mickleborough 2013). There are commonalities in models of fatigue, particularly towards the types of muscular action and intensity and duration of activity, for example, in prolonged activity slow twitch muscle may continue activation, whereas if intensity increases the activation of fast twitch motor units with high force production thresholds will decrease through a lack of central drive. This is of importance as the lack of central drive reduces the aforementioned muscular recruitment, firing rates, synchronisation and intermuscular co-ordination (Cormie, McCuigan and Newton 2011, Ross, Leveritt and Riek 2001).

The resulting effect of peripheral fatigue is shorter in duration as the clearance of metabolic by-products is all that is required, which can be achieved through periods of recovery or repletion of energy stores through nutrition. Whereas, with NF the effects are further reaching and more apparent and will depend on the mechanism of its inception. One manifestation has been discussed by Avela et al. (1999), Komi (2000), Mclellan, Lovell and Gass (2011) and Nicol et al. (1996) around the effects of reduced stretch-reflex sensitivity after exhaustive SSC exercise and this bears relation to rate of force development and PP. The SSC is incorporated into multiple measures of power due to its utility of all three types of muscle action (Cormack, Newton and McGuigan 2008, Komi 2000) alongside metabolic, mechanical and neurological elements and disturbance of stretch reflexes. One commonly researched product of the SSC is DOMS particularly through eccentric loading (Connolly, Sayers and McHugh 2003, Eston, Mickleborough and Baltzopoulos 1995, Hody et al. 2013, Nicol and Avela 2006, Semmler 2014). Eccentric loading is said to generate greater structural damage in comparison to concentric and isometric muscle actions to the muscle resulting in ultra-structural loss with decrements in performance depending on the training age of individuals, and severity of exercise, for up to eight days post eccentric activity (Byrne and Eston 2002, Kamandulis et al. 2010, Nicol and Avela 2006). This muscle integrity loss is a result of lengthening action of the muscle fibre, which in turn damages the sarcomere and components of the excitation-contraction coupling system (Byrne and Eston 2002, Eston, Mickleborough and Baltzopoulos 1995, Lovering and De Deyne 2004). Such damage of the force providing components or transmitting structure alters afferent signals to the CNS, therefore potentially altering the size and number of muscle actions thus reducing neuromuscular function and limiting ATP generation through lack of stimulus, which manifests as fatigue (Enoka 2008, Gandevia 2001).

Taking this into account Avela et al. (1999), Komi (2000), Mclellan, Lovell and Gass (2011) and Nicol et al. (1996) all identify reductions in performance due to alterations in muscle integrity and relate them to a bimodal trend involving an initial acute decline (Immediately post exercise), followed by an immediate recovery period, prior to a further secondary decline in measured values (approximately 2-3 days post exercise). Faulkner et al. (1993) reported from studies on mice that the initial decline is more from mechanisms of injury, whilst the second dip results from biochemical injury relating to phagocytic activity following the acute inflammatory response from the initial injury (Avela et al. 1999). This concurs with research upon humans which, immediately post SSC exercise, any declines are primarily metabolic disturbances due to desensitised mechanoreceptors, whilst secondary neuromuscular performance losses coincide with inflammatory responses indicative of the muscle damage occurring from eccentric loading (Dousset et al. 2007, Gandevia 2001, Nicol et al. 1996).

As McLellan, Lovell and Gass (2011) suggest, much research orientated towards the manifestation and time course of fatigue has been upon individuals within controlled environments (Komi 2000, Nicol et al. 1996). There are also key texts based around team sports and identify, even if not directly, the existence of this bimodal trend (Cormack, Newton and McGuigan 2008, Hoffman et al. 2002, Hoffman, Nusse and Kang 2003, Mclellan, Lovell and Gass 2011). There is however very little orientated to the fluctuations of power, or alternative measures, within rugby union (West et al. 2014). Overall there is the understanding that the magnitude to which fatigue occurs and the reasoning behind it varies including the duration and intensity of activity (Duffield et al. 2012, Mclellan, Lovell and Gass 2011), the type of work performed (Hoffman et al. 2002), and potentially the training age and ability of the individual, where it has been identified that there is a distinction in power in high and elite level athletes over those that are less skilled (Duffield et al. 2012, Gabbett 2013, Hoffman, Nusse and Kang 2003). Then there has to be consideration towards the combined effect of the earlier mentioned collisions, identified by indirect measures of CK, which in conjunction with multiple SSC bouts and eccentric loading will invoke muscle integrity loss.

In an investigation of neuromuscular function in rugby union, West et al. (2014) compared pre-match (36hrs) to post-match peak power output (PPO) at 12hrs, 36hrs and 60hrs of professional elite level players utilising a three CMJ protocol. The results showed that at 12hrs and 36hrs post-match PPO values were significantly less than baseline values, but returned for the majority to normal by 60hrs. Some players however had not returned to baseline PPO by this point. The magnitude of high intensity running loads, and indeed the number of collisions and contact, are attributed to this especially from a positional specific aspect. These fluctuations in values are similar to decrements of power observed in elite rugby league players by McLellan, Lovell and Gass (2011). At 30mins post- and 24hrs post-match play there is a concomitant significant decrease in both PPO and PRFD, whilst Peak Force (PF) is only significantly reduced at 30mins post-match before returning at 24hrs to 30mins pre-match values. It is not until 48hrs post-match that PRFD and PPO values return to 30mins pre-match values, therefore McLellan, Lovell and Gass (2011) highlights that the reduction of the velocity component of PP i.e. PRFD is more sensitive to fatigue than PF, and that PF is likely affected through the generation of metabolites and peripheral fatigue (Gandevia 2001, Nicol et al. 1996). Thus, PPO was the more sensitive measure to fatigue, which, once again relates to muscle damage and inflammatory responses from impact loads and collisions (Dousset et al. 2007, Gandevia 2001, Nicol et al. 1996). This does not exclude the benefit of having an understanding towards PRFD, because at 72hrs and 96hrs PRFD values were significantly greater than 30mins pre-match values, initiating the suggestion of improved recovery strategies and optimal training in order to return to pre-match function more readily. Furthermore, the delayed response identified by West et al. (2014) for some beyond the 60hrs post-match could simply be a matter of time courses of recovery being different amongst players as with Cormack, Newton and McGuigan (2008) and McLellan, Lovell and Gass (2011) as a direct response of the loads generated during competition.

Cormack, Newton and McGuigan (2008) also examined the acute response of the neuromuscular system in an attempt to find a sensitive measure of the resulting effect of impacts from game play using senior level elite Australian Rules football players. They reviewed both absolute and relative (to body mass) measures of flight time, mean power, relative mean power, relative mean force and flight time: contraction time through a single countermovement jump (CMJ1) and multiple countermovement jump (CMJ5) profiles from 48hrs pre-match, immediately pre- and post-match, 24hrs, 72hrs, 96hrs and 120hrs. Immediately post-match all measures were substantially decreased from between 1.5% and 16.7%. Although the magnitude of percentage change fluctuated, this decrement in performance remained at the 24hrs post-match mark. Unlike McLellan, Lovell and Gass (2011), there were no recordings for 48hrs, yet by 72hrs only CMJ1 mean power, CMJ1 relative mean power and CMJ5 flight time remained substantially decreased by 6.1%, 5.9% and 2.1%

respectively. At both 96hrs and 120hrs all measures were reported as either trivial or unclear with the exception of CMJ5 flight time being substantially decreased once more at 120hrs post-match by 1.5%. Although no values are given for peak and relative PP variables it is mentioned that immediately post-match there was an increase in values, which would be indicative of forms of potentiation and a heightened state of the neuromuscular system as a direct result of activity (Young and Behm 2003). This is also found in both American football by Hoffman et al. (2002), and women's soccer by Hoffman, Nusse and Kang (2003), although as is further stated it is unclear why these should be increased in the presence of decrements for all other values. The immediate post-match decrements of mean and relative mean power and continually suppressed values until 72hrs post are likely a reflection of the effects of neuromuscular or low frequency fatigue. This will manifest through alteration in the mechanics of technique through aspects such as a decrease in the stiffness and strength of the knee extensors (Toumi et al. 2006), or delay in recovery of the neuromuscular system subsequently effecting afferent signals from damage caused from the demands of play thus reducing the athletes capability to perform maximally (Enoka 2008, Komi 2000).

Progressing from the initial study over one pre-season match and its subsequent training week Cormack, Newton and McGuigan (2008a) have the only study reviewed which extended the examination period of neuromuscular and endocrine systems throughout the length of the season (22matches). In this instance they utilised CMJ1 and CMJ5 flight time: contraction times, confirming the sensitivity of the measure in relation to recovery and NF. It was found that on 60% of occasions comparing pre- to post-match CMJ1 flight time: contraction times they remained substantially reduced; whilst CMJ5 on only three of the matches indicated substantial decrements from pre-match values. Of interest in this instance however are the post-match durations whereby substantial decrements are identified for durations between 72hrs and 144hrs post-match, but no other prior time frames are detailed. When relating these durations to previous studies this could in fact be a result of the bimodal trend in its second stage but could also be as a result of an impact of training through the normal training week. This is referred to by Cormack et al. (Cormack, Newton and McGuigan 2008) and state that there is no true indicator to suggest that any decrements are as a result of central or peripheral fatigue, although once again changes in muscle tendon stiffness and changes in hip and knee angles from prior SSC exercise is the likely candidate. Furthermore they suggest that were the decrements due to periods of non-functional overreaching or overtraining, longer periods of substantially decreased values would be evident. Whereas, in this particular study the longest duration is five weeks, although within that time period there was a period of one to two weeks where data was not collected therefore no true conclusion can be made.

Although using the measure of peak height (PH) from the CMJ in conjunction with muscle soreness ratings and CK changes, Andersson et al. (2008) monitored performance in female Scandinavian football players over two matches within a 74hrs period whilst utilising both active and passive recovery strategies. Immediately after the match peak height (PH) differences were significantly lower with a reduction of 4% coinciding with increased CK and muscle soreness scores. In this instance there were no significant differences in recovery for all performance measures between both the active or passive groups, and PH from CMJ still remained significantly lower than 3hrs pre-match throughout all subsequent time markers up to 74hrs. This therefore suggests that the women had not recovered fully prior to the next match commencing. This is despite measures of CK and perceived muscle soreness scores returning to baseline. The reasons given by Andersson et al. (2008) for the change in PH from CMJ values is that of the high force muscle actions generated within the game causing myofiber structural disruption, which is identified in the increase in CK. This could suggest however, as stated by Andersson et al. (2008), that the measure of PP as per Hoffman, Nusse and Kang (2003) may have more accuracy over PH and that similar findings of McLellan, Lovell and Gass (2011) with PRFD may be attributed to PH's continual low values.

Ronglan, Raastad and Børgesen (2006) also review PH from CMJ, over a one week training camp comprising of four training sessions within international handball players ranked within the top ten of the world. Over this time sessions were of moderate to high intensity ranging from 80-120mins and one low intensity recovery session on day three. A similar group of handballers were monitored for the same parameters, which also included isokinetic knee extension and a 20m sprint, during an international competition involving three training days prior to three competitive matches over three consecutive days. Training sessions for the international tournament were low to moderate in intensity and kept to 60mins. During the training camp both knee extension strength and CMJ PH showed the greatest significant difference with an 8.4 ± 1.7% and 6.9% ± 1.3% respective reduction on the second and third day of training. Immediately post-session three on the second day saw the greatest reduction in CMJ PH values (5% - 6%) when comparing pre- to post-session values. There were smaller but still significant differences in 20m sprint performance at the same time intervals. In this instance the metabolic cost is likely to be the reason for decrement immediately post-game but the cumulative neural effect of fatigue will result in pre-session values. This is particularly relevant in the instance of a 48hrs rest period whereby PH values are still significantly less than baseline measures 90hrs from the commencement of training. One aspect that is interesting however, despite no mention, there is a concomitant increase in isometric knee strength alongside PH from 40hrs but PH sees another decline whilst knee strength increases by 4%. This once more is cognisant with the findings of McLellan, Lovell and Gass (2011) in their findings of PF recovering more rapidly than PP with the velocity component being affected due to more neurological disturbances and structural integrity loss aspects as a result of high intensity activity including contact, eccentric loading and physical loading.

Similar testing of handball players by Ronglan, Raastad and Børgesen (2006) within an international tournament resulted in significant decrements of 3.7% ± 0.4% and 6.7% ± 1.3% respectively for PH from CMJ and 20m sprint performances over the three match period. At this stage Ronglan, Raastad and Børgesen (2006) highlight that immediately prior to the first match, which was subsequent to three days of training, that there was already a significant decrement in 20m sprint times in comparison to pre-training and tournament baselines followed by a further decrease immediately post-matches two and three. This clearly suggests the need for recovery but also the cumulative effect of multiple sessions on performance. The number of subjects (Training n=7, Tournament n=8), and the lack of control group are suggested as limitations, however with regard to decreased 20m sprint performance within the tournament prior to any matches taking place could be indicative of the effects of NF on speed mechanics from prior training, which would be within the time frame of a bimodal trend in performance as per Komi (2000) and Nicol and Avela (2006). It should also be noted that within handball, rolling substitutions are in use leading to large variations in playing time over the three matches (44-134mins) suggesting that the metabolic cost in regards to recovery and the cumulative effect of NF will vary within the small numbers of subjects.

It is clear however that the time frames for the manifestation of NF may vary, but this potentially is down to the work generated according to the sport. In contrast to the above findings of Andersson et al. (2008), McLellan, Lovell and Gass (2011) and West et al. (2014) it is found by Hoffman et al. (2002), using American footballers split into starters and non-starters, that there are no significant differences between immediately pre- or post-match CMJ and squat Jump (SJ) PP or PF values for both groups. There is however a significant decrease in these values for both groups at the end of Quarter 2 of the game for the SJ values, whilst the CMJ values decrease but with less significance in comparison. This is related to the concentric component being more readily fatigued in the starters whilst the non-starters are likely to have lost the benefit of the pre-match warm up, especially in temperatures of 10°C resulting in blood shifting from the peripheries to the core to maintain core temperature.

There are similar pre- post-match non-significant changes in PP and PF found by Hoffman, Nusse and Kang (2003) for starter and non-starters in female soccer, they do however find a subsequent respective 15.5% and 12.4% significant decrease occurring at 24hrs post-match for the starters which Hoffman et al. (2002) does not continue to review. This does suggest that players are able to maintain PP and PF values following a match. However, no changes in both pre- post-match could be similar to that suggested by Cormack, Newton and McGuigan (2008) in that a form of neural potentiation, an increase in muscle contractile performance, as a result of contractile activity (Comyns et al. 2011, Cormie et al. 2010), may occur which could also possibly give reason behind the lesser decrease in values at the end of Quarter 2 by Hoffman et al. (2002) for PP and PF from CMJ. Also in both cases particularly with the American footballers it is clearly stated that substitutions were widely used thus resulting in playing durations of 13mins – 90mins, which would affect the accuracy of results and could simply suggest that players did not reach exhaustion (Nicol and Avela 2006). Furthermore, for both in relation to substitutions the more senior players may also have greater ability to recover once play has stopped or they are substituted (Hoffman et al. 2002).

A further aspect of an athlete's training week is the continuation of training once they have recovered. This potentially is a shortfall with the majority of studies whereby the ongoing effect of training and the mechanical loading also has importance alongside a need for recovery, but unfortunately most research is typically only over very short periods of time. McLean et al. (2010) identified that there was a significant decrease in CMJ flight time 24hrs post-match as per Cormack, Newton and McGuigan (2008) before returning to base levels by four days post-match, but this was not the case for CMJ relative power. There were however significant and consistent reductions from the power measurement between seven and nine day micro cycles, which ties in with the suggestion from West et al. (2014) and Gee et al. (2011), whereby training sessions typical in team sports environments may also effect NF for 48hrs post exercise. This then places emphasis upon the need for returning to as close as possible to the pre-match values through optimal recovery in order to reduce any accumulative effects of playing and training. This therefore requires a measure that is sensitive enough to detect performance decrements.

2.5 Measurement of fatigue and power:

With the need for a return to baseline measures of power and an assessment of recovery from both training and match play, the assessment itself that is chosen is critical in alerting to the impact of the components of play on the neuromuscular system and manifestation of fatigue. Providing factors of pre-test protocols, testing conditions, equipment and technique are consistent then power has the highest reliability in terms of NF hence its regular use in team sports (Fowles 2006, Hopkins, Schabort and Hawley 2001, Mclellan, Lovell and Gass 2011, Ronglan, Raastad and Børgesen 2006). However, the technique of testing within an applied environment needs to be realistic and repeatable, but also applicable to the sport itself whilst taking into account the cross section of non-homogenous positional groups within a team but also the time available within a training or competitive week.

Komi (1987) and Komi (2000) examined through the use of an invasive technique the effects of altered muscle mechanics as a result of reduced tendon stiffness. This was also identified by Nicol (1996) and Toumi et al. (2006), in conjunction with reduced stretch reflex sensitivity upon force potentiation mechanics. Whereas this research in its completion crucially highlights the bimodal trend, which has relevance to future research, it is completely impractical in its use of an attached buckle transducer through surgical interventions under local anaesthesia to an individual’s Achilles tendon. Similarly, concerns towards practicalities arise from the use of artificial stimulation of the muscle fibres to generate muscle actions. With these procedures the muscle will be activated synchronously which is not the case in voluntary muscle activation, but also, as is common in these types of research, a greater amount of energy is utilised in comparisons to athletic performance in order to gain results, therefore offering a skewed perspective on performance (Enoka 2009). This is not however to suggest that the measures are not effective, but to say that the dynamics by which the muscles are recruited are not in a sports specific manner. Indeed measures such as isometric muscle contractions such as those researched by Aagaard et al. (2003), Byrne (2002), and Thomas, McLean and Palmieri-Smith (2010) are specific when relating to testing physiological function from the perspective of injury and rehabilitation but in relation to physical recovery from fatigue and a return to full functionality other measures are more beneficial.

All previously mentioned research utilise either the CMJ or the SJ in order to generate their relevant measures. For both Hoffman et al. (2002) and Hoffman, Nusse and Kang (2003) the SJ is the mode used in examining performance measures within American football and Women’s soccer in conjunction with the CMJ. When looking at both types of jump in terms of specificity it could be raised that the SJ removes the eccentric component from the jump thus leaving only the concentric action, which for some team sports such as rugby union is not relevant as it may only be in a scrum where this type of action is performed. Otherwise all other actions such as sprinting, COD, jumping all utilise the SSC and that is where the CMJ has more relevance. The CMJ is the most popular for its inclusion of neurological, metabolic, and mechanical elements, and for its utility of the stretch reflex (Ross, Leveritt and Riek 2001). Also, from many perspectives, it is considered an effective and reliable indicator of NF both from an acute and chronic perspective through consecutive playing and training cycles (Cormack et al. 2008a, Cormack, Newton and McGuigan 2008, McGuigan, Cormack and Newton 2009, McLean et al. 2010, Twist and Highton 2013).

The elements of PP and the use of the CMJ have been shown to be effective in measuring the effects of NF. Alongside this, and to bolster the use of PP from a CMJ as a measure, is its sensitivity in comparison to other measures of muscle infrastructural loss at similar time frames. Once again there is evidence to suggest that providing an accurate measure of impact loading that correlates to power values can be found it could be possible to provide a measure that is capable of enhancing training and recovery loads which can only benefit applied environments.

2.5 Overview:

Therefore, overall it is identified that impact and collision loads have a deleterious effect upon performance. The majority of investigations previously related to its manifestation through physical time loss injuries and indirect measures of bio-markers such as CK, which is released as a direct result of the infrastructural damage from external forces. Concomitant relationships have been identified between bio- and performance markers but as yet nothing exists where direct measures of impacts have been directly related to the performance measure of PP. From a performance perspective within rugby union, power is utilised for many components of game play and has been proven to hold more credibility over measures of PF for example because of the mechanisms incorporated in its generation and the time courses to which it is effected by workloads, which are also similar to the components of NF. Technology such as GPS has the potential to assist in identifying relationships between these two facets, whereby accelerometry is able to provide a three dimensional perspective of mechanical, but more importantly impact loads, thus able to provide the magnitude of impacts more accurately over that of video or notational analysis.

3.0 Method

3.1 Experimental Approach:

A GPS was used to classify and measure impacts during training and match play. Over a period of twelve weeks during the in-season months of September to December, all players training data were collected including all rugby orientated training sessions, the data for which are presented only for those participants who completed all rugby training sessions available to them. Match-play data was collected from twelve matches from a combination of domestic competitions including the Aviva Premiership, Amlin Challenge Cup and the LV Cup. No duration of play limits were set for data collection and at this stage no positional groups were taken into account. The neuromuscular response to impacts through the measure of PP, was recorded bi-weekly using a force platform (AccuPower Portable Force Platform System; Software is AccuPower by Athletic republic version 1.6.3) on the first returning day post-match and immediately prior to the last training session of the week, approximately 24hrs pre-match. Only players fit to perform or cleared by medical staff performed the CMJ. If for any reason a GPS unit was not worn but the training session completed their data was not included in the dataset.

3.2 Participants:

Twenty nine elite male rugby union players, age 26 ± 4 years, height 185.2 ± 7.9 cm, and mass 101.7 ± 13.1 kg; mean ± SD, were all tested as per standard in-season weekly monitoring. All participants were previously aware of any required procedures for PP testing and accustomed to wearing GPS units during training and match play. Written informed consent was obtained by all participants and the study was approved by the Coventry University Ethics Committee.

3.3 Global Positioning System Unit:

The Minimax S4 10 Hz (Catapult Innovations, Melbourne, Australia) GPS unit is a commercially available device. These units through their inbuilt accelerometry have been identified as being reliable in identifying instances of impact within both controlled laboratory conditions, but also field testing, and determined accurate in detecting changes in physical activity and also detecting impact loads within collision sports (Boyd, Ball and Aughey 2011, Gabbett, Jenkins and Abernethy 2010). During training sessions the GPS unit is worn inside a padded pouch within a specifically designed skin tight vest which stabilises the GPS unit within the upper thoracic area between the shoulder blades. For match data recording the skin tight match shirt also has a padded inbuilt pouch which stabilises the GPS unit in a similar position.

3.4 Impact Load measure:

All on field rugby specific training sessions and competitive match play were recorded through GPS and data extracted using Catapults Sprint 5.1.0.1 software. Each unit was turned on for satellite acquisition at least 20 minutes prior to activity commencing. Similar procedures were observed for match play, however, due to separate match shirts being worn for both warm up and game play, and time available between the warm up finishing and match commencing, it was only possible to record GPS data from match play itself, therefore data within the warm up was not included. It is recognised that impacts will not be registered within this time frame, however due to the inconsistent nature of the warm up it is not possible to simply assign an arbitrary number to each player. Data was extracted regardless of durations of training or match play as it is the exposure and accumulation of impacts that is pertinent as opposed to the duration of play or training.

The impacts themselves were registered using Catapults proprietary tackle detection algorithm, titled "Tackle Load". The algorithm is specifically designed to identify events with the same physiological profile of a tackle specific to rugby union and rugby league, the data for which is generated from an internal accelerometer (3 axis 100 Hz) within the GPS unit. Due to the commercially sensitive nature of the algorithm used for the impact zones it is not possible to quantify impact loads or add weight to the individual zones in order to assign a cumulative load. Therefore, for this study a cumulative impact count of all impacts has been used based upon the default tackle loads zones categorised by the Sprint software itself (See **Table 1**).

Table 1: Default impact loads categorised within individual zones.

	Low	High
Zone 1	0	1
Zone 2	1	2
Zone 3	2	3
Zone 4	3	4
Zone 5	4	5
Zone 6	5	7
Zone 7	7	10
Zone 8	10	15

Although there are 8 zones in total, only impacts within zones 1-5 were registered. Due to the commercial sensitivity of the algorithm resulting in an inability to identify the magnitude of impacts it can only be interpreted that impacts within zone 6-8 are of a magnitude greater than players had been exposed to and were therefore not registered.

These events are however not limited to a tackle event. According to World Rugby (2015) Law 15, a tackle occurs “when the ball carrier is held by one or more opponents and is brought to the ground”. Therefore, to remove any confusion and to use a term more in context within the environment, an impact, in the instance of this study has been used to describe an event not limited solely to actual player on player contact through tackling but a high impact event which may include contact with the ground or another player i.e. diving to score a try, entering a ruck, entering a maul, or even impact off the ball. The accuracy in registry of these impact loads by the Catapult units has been determined by Gabbett, Jenkins and Abernathey (2010) with strong correlations identified between video analysis of impact events and the catapult values produced.

In order for an impact to register all of the following criteria must be met.

- A non-vertical event must occur whereby, for greater than 0.75secs, a players orientation is altered beyond its normal of -30° and 60° for pitch attitude, and roll attitude of -45° and 45°.
- A player must exceed a minimum threshold of physical activity prior to the non-vertical event. This threshold is pre-configured within the software and is accelerometry based where the minimum acceleration magnitude is 2.0g. Grappling is included within this criteria but may also include for example acceleration or deceleration.
- A spike in player load occurs (defined as an increase of 2 player load units) prior to the non-vertical event. Player Load is a software exertion measure not dependent on distance, the magnitude or scaling factor of which is commercially sensitive. This event is not limited to, and is not required to involve, purely tackling or being tackled thus resulting in player on player contact, but can be registered from for example clearing out a ruck or entering a maul (Lawrence 2015).

As a rudimentary guide for orientation to the grading of impacts, Gabbett, Jenkins and Abernethy (2010), who also using Catapult devices, grade the intensity, based on video analysis of play, as mild (equivalent of zone 1-2), where a player is tackled but able to continue motion out of the tackle itself, moderate contact (zone 3-4), whereby forward motion or momentum continues until the tackle is completed, or heavy (> zone 4), resulting in the players forward motion being halted and forced backwards in the tackle. As determined previously however, this is simply a guide, as the physical characteristics of the player, positioning of the impact upon the individual and locomotive aspects of the game leading to the impact will alter the magnitude of the event.

The criteria for the recording of an impact also causes an issue in terms of the engagement of a scrum. Prior to the engagement the referee calls for the opposing plays to “crouch”, then “touch” (brief gripping by both the tight and loose head props, of their respective opponents shirt on the back or side), followed by a short pause before the referee calls for the scrum to "Engage", thus initiating the engagement of the two teams. Therefore, in this instance, the use of tackle loads from the Catapult software becomes obsolete. Prior to the engagement of players, as a direct result of the referee effectively pausing the players through the process of crouch (4secs), touch (1.7secs) and engage, there is no precursory activity to enable the algorithm to record an impact (Cazzola et al. 2015). The accelerometers also do not have the ability to communicate with each other, therefore are unaware that all eight players are moving in unison during the setup of, and engagement of the scrum, therefore not allowing the unit to identify a scrum as being in place or indeed the registry of the impact. Consideration has been given to the issuance of an arbitrary impact instance as a result of the non-registry of each impact during the engagement phase by the Catapult unit. However, as the magnitude of forces produced within each scrum are known to vary throughout each position (Milburn 1990), and due to fact that the magnitude of the forces which would constitute the recording of an impact event are not known due to the proprietary algorithm of the tackle load, no true relationship can be made between the two. Therefore is has not been possible to apply an arbitrary value to the engagement impact, thus must be taken as a systematic aspect of the game, but also becomes a limitation of this study in terms of impact load registry and its affect upon NF.

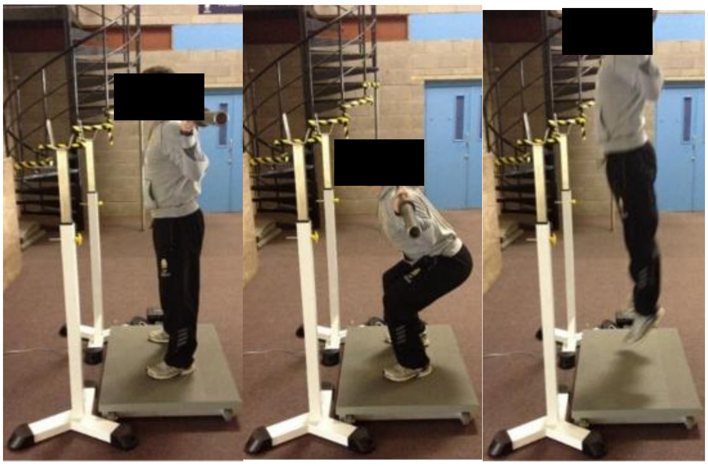

Figure 1: Countermovement Jump sequence as per peak power testing protocol.

3.5 Power testing:

On each occasion all participants performed an individual warm up of five minutes of myofascial release, and five minutes of dynamic flexibility or mobility work (Peacock et al. 2014). Three practice unloaded countermovement jumps were performed followed by one minutes rest before positioning themselves in a standing position on the force platform at a self-selected foot width. The participant performed a further three countermovement jumps with an external load of 20kg

(Standard Olympic bar) placed across their upper trapezius (Hansen, Cronin and Newton 2011, Hori et al. 2007). Each jump was performed to a consistent self-selected depth prior to the immediate performance of a maximal jump with a distinct pause and resetting of position separating each repetition performed (See **Figure 1**). There were no concerns over learning effect as this type of jump is performed on a regular basis by all participants. Raw PP data was collected using an AccuPower portable force platform system with Hall effect technology, sampling at 400 Hz, which was positioned on a flat concrete floor. The portable system allowed ease of use within the applied environment whilst the dimensions of the platform (762 x 1016 x 124 mm), 8,900 N-Fz capacity, and built-in overload protection, allowed for players of all body mass's to perform the weighted CMJ. This method of multiple CMJ's upon a portable platform has been considered valid when measuring PP both inter- and intra-day by Cormack et al. (2008b) and is supported by Twist and Highton (2013) and Walsh et al.(2006). The data itself was reviewed and exported using Accupower by Athletic republic (version 1.6.3) with the value used being the mean of the last two jumps on each occasion as per Hopkins, Schabort and Hawley (2001), but predominantly from a practical point of view where the first jump with the bar in place regularly resulted in inaccurate values and were therefore omitted. All outlying data values were removed as a matter of routine during live testing of players which would be a common practice in the applied environment.

3.6 Training and Recovery breakdown:

The day upon which a match is played determines the training week structure and duration but also the subsequent recovery period leading to the training week (See **Table 2** and **Table 3**). A Friday match (kick off 19:45hrs) always resulted in a 72hr recovery period prior to returning to the subsequent training week. However, recovery after a Saturday or Sunday match (Kick off times will vary) depended upon the subsequent match day i.e. Saturday matches to a Friday night had a three day training week (See **Table 4**). The intensity and level of physical contact within training also varied in accordance with the duration between matches i.e. a three day turn around had limited volume and density of work with little or no contact.

Table 2: Typical three day training week breakdown

Day	Session	Duration	Type
1	Testing		Peak Power Testing
	Weights	45-60 mins	Upper or Lower body resistance weights (No GPS)
	Units/Skills	45-60 mins	Positional group tactics and skill development (Semi or Full Contact)
	Rugby	30-60 mins	Standard team rugby training (semi or Full contact)
2	Units/Skills	45-60 mins	Positional group tactics and skill development (Non or Semi Contact)
	Rugby	60 mins	Standard team rugby training (Non or Semi Contact)
3	Testing		Peak Power Testing
	Captains Run	20-30 mins	Units and Match day squad team tactics and play rehearsal (Non contact)

Table 3: Typical four day training week breakdown

Day	Session	Duration	Type
1	Testing		Peak Power Testing
	Rugby / Conditioning	30-45 mins	Conditioning games or standard high intensity conditioning
2	Weights	45-60 mins	Lower body resistance weights (No GPS)
	Units/Skills	45-60 mins	Positional group tactics and skill development (Semi or Full Contact)
	Rugby	60 mins	Standard team rugby training (semi or Full contact)
3	Weights	45 mins	Upper body resistance weights (intermitent)
	Units/Skills	45-60 mins	Positional group tactics and skill development (Non or Semi Contact)
	Rugby	60 mins	Standard team rugby training (Non or Semi Contact)
4	Testing		Peak Power Testing
	Captains Run	20-30 mins	Units and Match day squad team tactics and play rehearsal (Non contact)

Table 4: Training week and recovery period breakdown

Training Week Duration	Training Days	Match Day	Post-Match Recovery Period
3 Days	Monday, Tuesday, Thursday	Friday	72hrs Recovery
4 Days	Monday,Tuesday, Wednesday, Friday	Saturday	48hrs Recovery
4 Days	Monday, Tuesday, Thursday, Saturday	Sunday	48hrs Recovery

3.7 Statistical Analysis:

Data is detailed as the mean ± standard deviation. Relationships between zoned impacts and PP difference were analysed using linear regression analysis. The significance of change in PP values during either a three or four day training week or as a result of 48hrs or 72hrs of recovery were identified with Independent Samples T-Test or Mann Whitney U depending on normality. Interactions between recovery durations were determined with a mixed-model design ANOVA. Normal distribution of data was tested with the Shapiro-Wilk test ($p < 0.05$) whilst in order to increase the application of this research the Effect Size (ES) statistic was used to determine the magnitude of change with values <0.2 = trivial, 0.2 - 0.5 = small, 0.6 - 1.1 = moderate, 1.2 - 1.9 = large and >2.0 = very large (Hopkins 2003). This was calculated using the following formula: ES = (M1 − M2)/s, where M1 = mean of one group, M2 = mean group two, s = standard de $(\sqrt{SD1^2+SD2^2/2})$ through Microsoft Excel 2013 (Cormack, Newton and McGuigan 2008). All other statistical analysis was performed using the Statistical Package for Social Sciences (SPSS for Windows, Version 17.0.2, SPSS, inc, Chicago, IL) with an alpha level of $p<0.05$.

4.0 Results

4.1 Three day training week:

In the case of a three day training week the analysis has established a negative correlation between all impact zone values to peak power difference. There were significant ($p < 0.05$), weak negative correlations between peak power difference and zone 2 ($R^2 = 0.124$, p = 0.024) and zone 3 ($R^2 = 0.107$, p = 0.037) with a stronger negative correlation with zone 5 ($R^2 = 0.401$, p = 0.001), yet no significant correlation between zone 1 ($R^2 = 0.073$, p = 0.117) and zone 4 impacts ($R^2 = 0.031$ p = 0.308). A significant negative, weak, correlation exists between the total number of instances and peak power difference within this time period ($R^2 = 0.136$, p = 0.018).

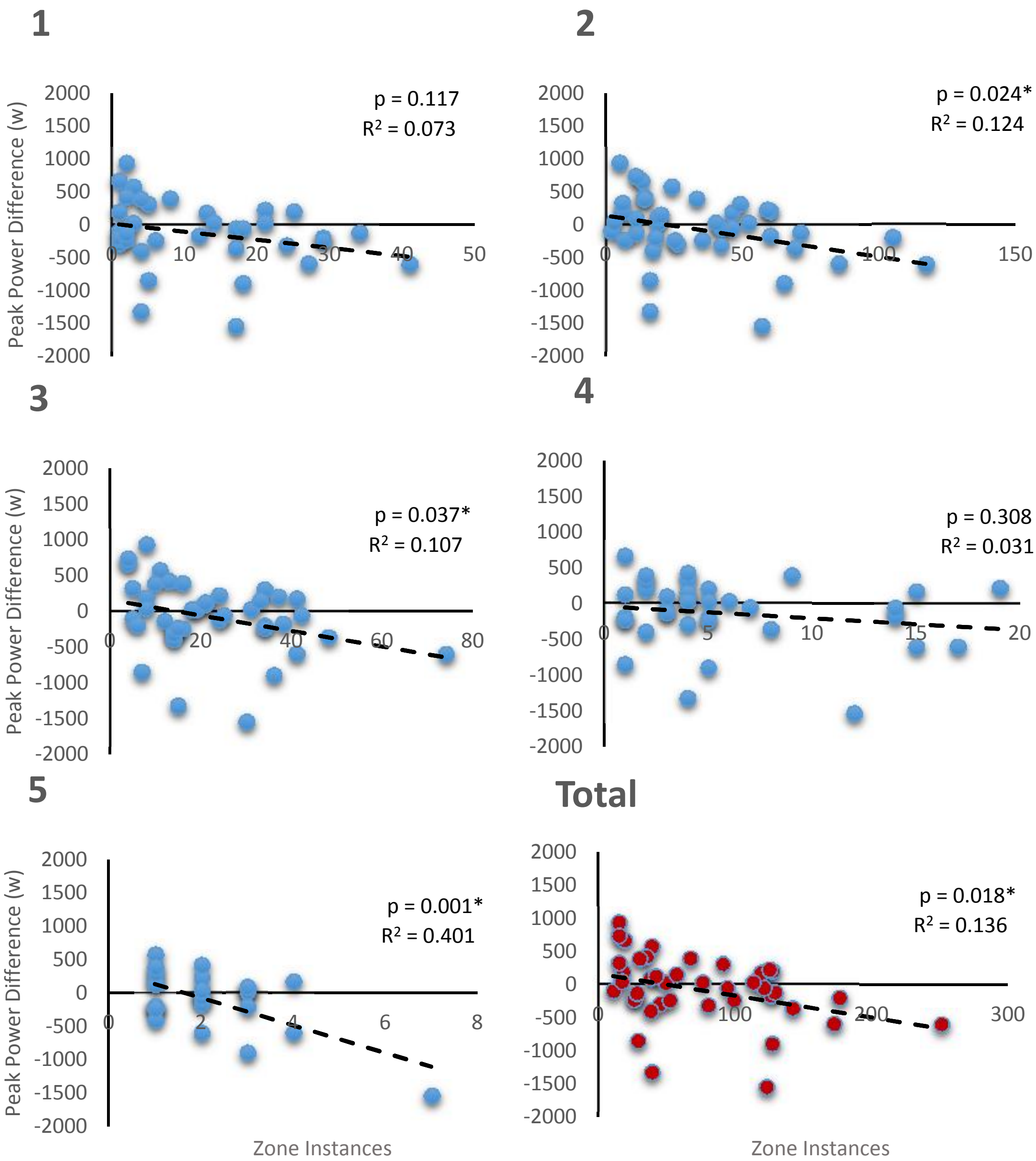

Figure 1 Relationship between Zone 1-5 and total impacts, and peak power difference from a three day training week, each mark representing peak power difference in relation to the number of impacts within that particular zone.

4.2 Four day training week:

Analysis during a four day training week also identified a negative correlation between instances of impact zone values 2, 3, and 5 values to peak power difference. Whilst in this instances zone 1 and 4 impacts were the only instances to have a positive correlation. There were no significant ($p < 0.05$) correlations between zone 1 ($R^2 = 0.111$, $p = 0.068$), zone 2 ($R^2 = 0.020$, $p = 0.444$), zone 3 ($R^2 = 0.007$, $p = 0.646$), zone 4 ($R^2 = 0.008$, $p = 0.646$) and zone 5 ($R^2 = 0.000$, $p = 0.961$) and peak power difference. A weak correlation between the total number of instances and peak power exists within this four day training week period ($R^2 = 0.001$, $p = 0.852$) with no significance.

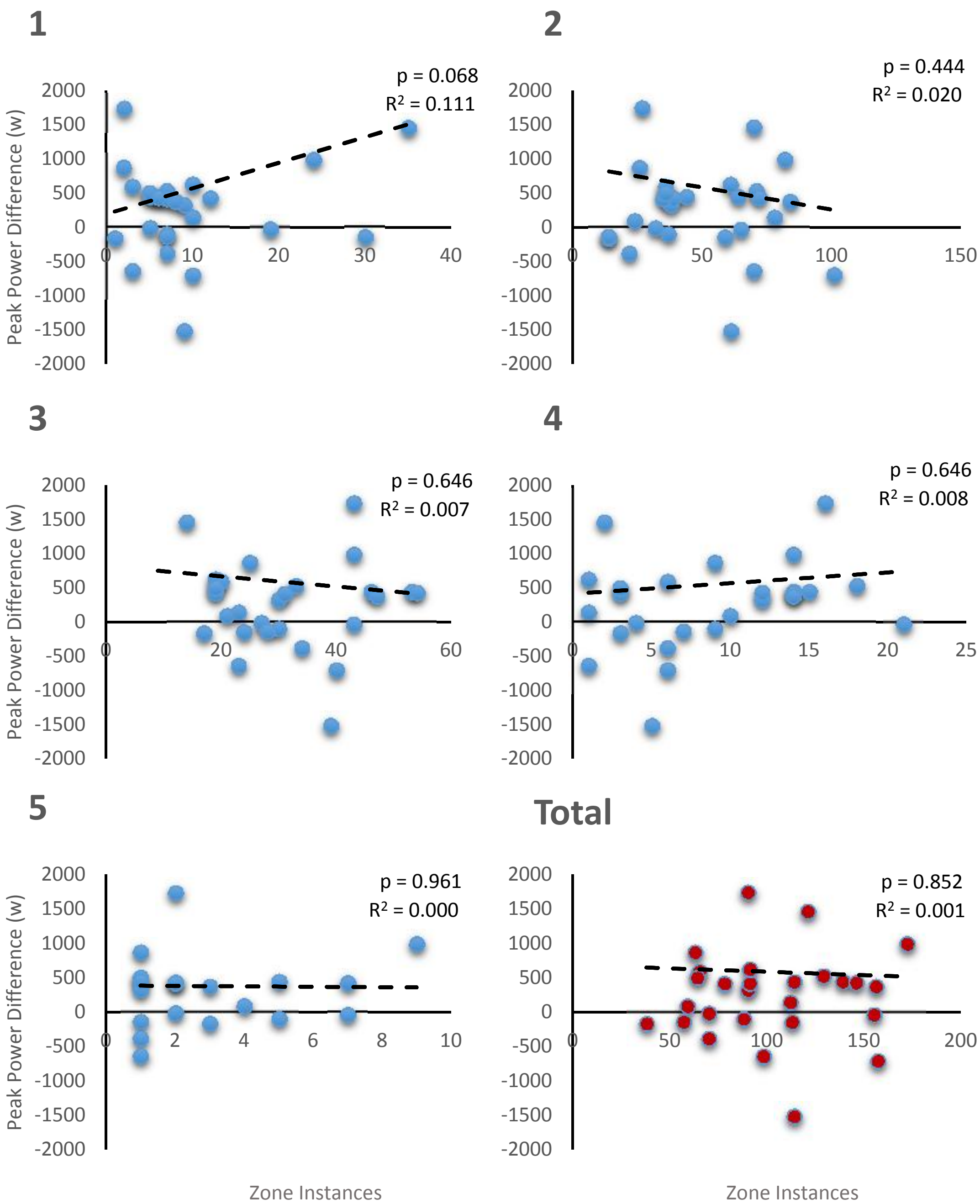

Figure 2 Relationship between Zone 1-5 and total impacts, and peak power difference from a four day training week, each mark representing peak power difference in relation to the number of impacts within that particular zone.

4.3 Match Recovery Period (48hrs):

In terms of differing post-match recovery intervals analysis shows a negative correlation between all instances of impact zone values to peak power difference after 48hrs of recovery. There were no significant ($p < 0.05$) correlations between zone 1 ($R^2 = 0.009$, p = 0.621), zone 2 ($R^2 = 0.007$, p = 0.599), zone 3 ($R^2 = 0.000$, p = 0.890), zone 4 ($R^2 = 0.005$, p = 0.648) and zone 5 ($R^2 = 0.015$, p = 0.446) and peak power difference within this same period. A weak correlation exists between the total number of instances and peak power difference within this 48 hr time period ($R^2 = 0.001$, p = 0.852).

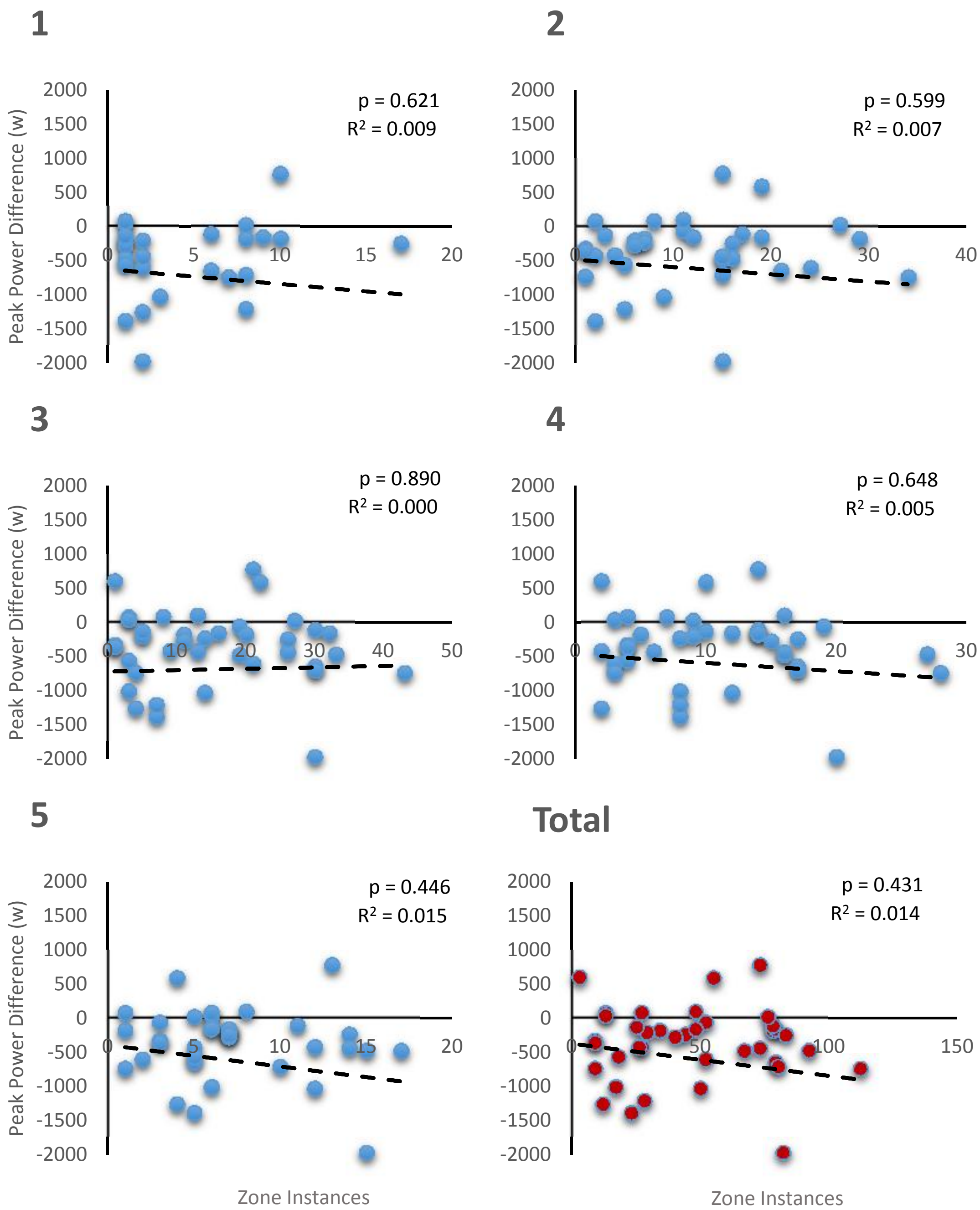

Figure 3 Relationship between Zone 1-5 and total impacts, and peak power difference from a 48hr recovery period, each mark representing peak power difference in relation to the number of impacts within that particular zone.

4.4 Match Recovery Period (72hrs):

At the extended recovery period of 72hrs post-match, with the exception of zone 5, negative correlations between all instances of impact zone values to peak power difference exist alongside very low relationships. There were also no significant ($p < 0.05$) correlations between zone 1 (R2 = 0.025, p = 0.586), zone 2 (R2 = 0.002, p = 0.834), zone 3 (R2 = 0.013, p = 0.583), and zone 4 (R2 = 0.017, p = 0.537). Zone 5 was the only zone that had a positive and significant correlation (R2 = 0.034, p = 0.379) with peak power difference within that period. A weak negative correlation between the total number of instances and peak power exists within this recovery time period (R^2 = 0.019, p = 0.512).

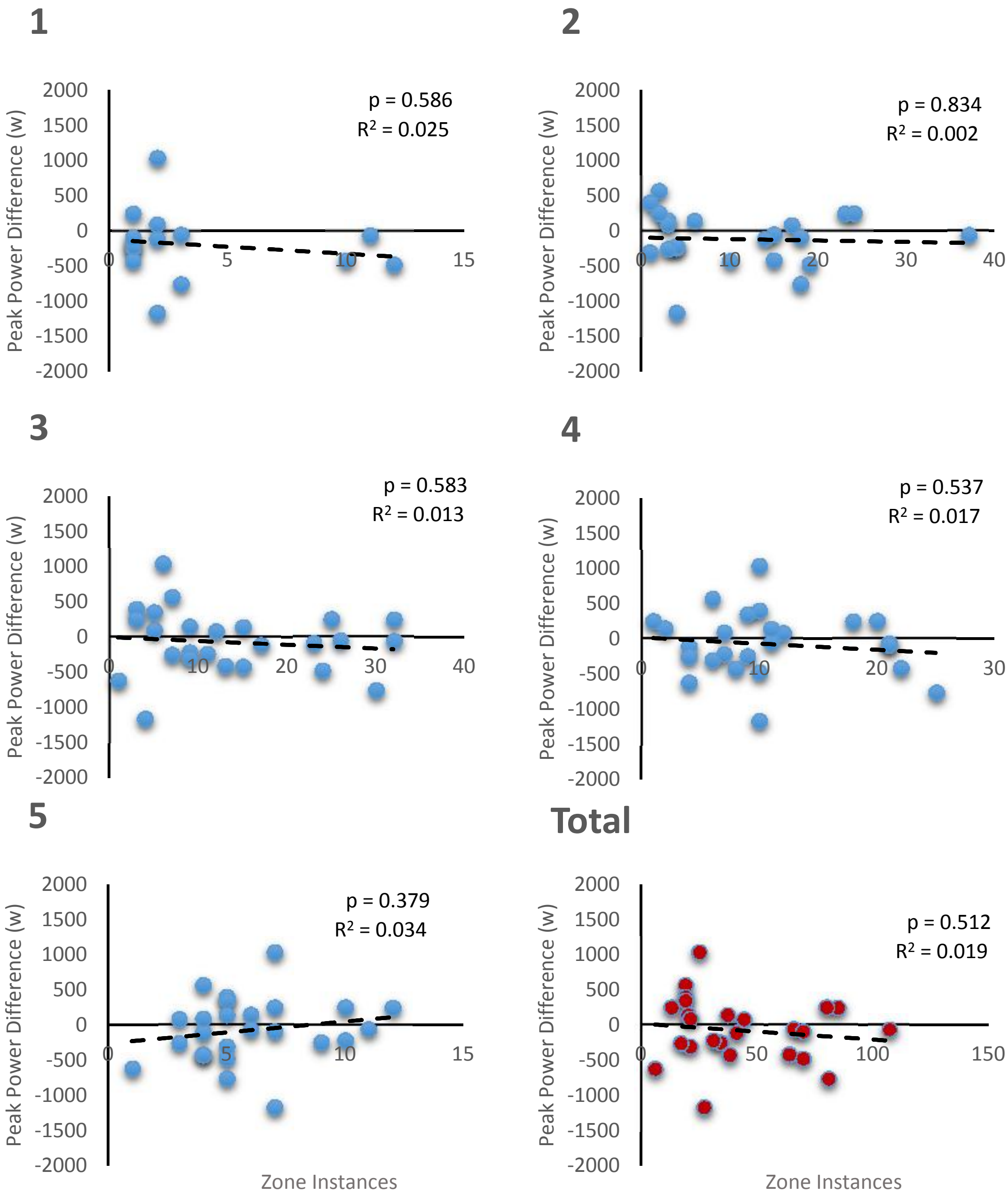

Figure 4 Relationship between Zone 1-5 and total impacts, and peak power difference from a 72hr recovery period, each mark representing peak power difference in relation to the number of impacts within that particular zone.

4.5 Instances of Impacts per zone:

A comparison of zoned impact instances and totals are shown in **Table 4**, where an Independent samples t-test determined differences between accumulated zone impacts in 3 day training weeks and 4 day training weeks. There were significant increases in zone 2 ($p = 0.019$), zone 3 ($p = 0.009$) and total impacts ($p = 0.021$) but not in zone 1, zone 4, or zone 5.

Table 4: Sum of within zone impacts registered. *indicates a significant difference ($p < 0.05$) between 3 Day and 4 Day training week zone and total impact instances.

Impact Zone	3 Day Training Week	4 Day Training Week	48Hrs Recovery	72Hrs Recovery
Zone 1	12.3 ± 11	10.9 ± 9.2	5.9 ± 4.8	3.7 ± 3.9
Zone 2	35 ± 27.8	49.7 ± 22.2*	13 ± 9.6	11 ± 9.4
Zone 3	22.2 ± 14.8	30.9 ± 11.6*	16.3 ± 11.4	13.7 ± 9.6
Zone 4	6 ± 5	8.4 ± 5.5	11.2 ± 6.7	10.7 ± 6.6
Zone 5	2.2 ± 1.4	3 ± 2.4	7.3 ± 4.2	6 ± 2.6
Total	74.2 ± 54.9	100.9 ± 35.1*	49.5 ± 29.8	42.2 ± 26.9

4.6 Training week and pre- to post-match peak power variations:

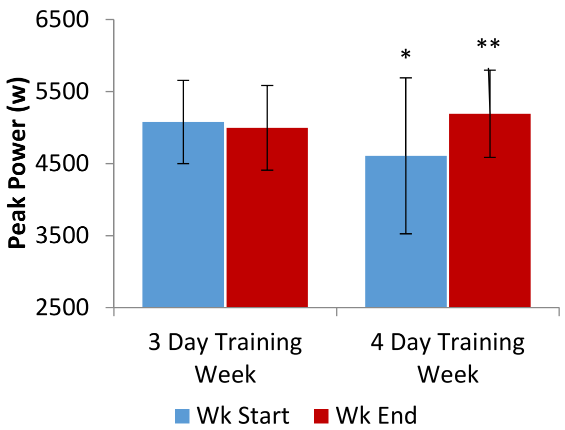

Figure 5 Peak Power comparison between a three and four day training week
*indicates a significant difference ($p < 0.05$) between 3 day and 4 day Week Start peak power values.
** indicates a significant difference ($p < 0.05$) between Week Start and Week End peak power

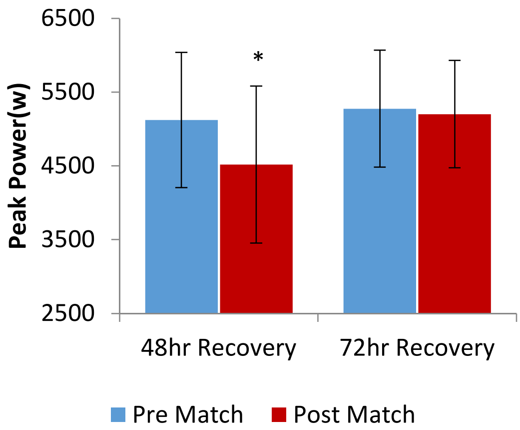

Figure 6 Peak Power comparisons between 48hr and 72hr recovery periods
*indicates a significant difference ($p < 0.05$) between recovery period peak power values.

An Independent samples t-test determined differences between week start (5077 ± 578w) and week end (5002 ± 579w) peak power values following three days of training but a statistically non-significant difference was found ($p = 0.553$). However a trivial reduction in power was identified (ES = 0.14) (See **Figure 5**). Alternatively for four day training weeks there were statistically significant differences ($p = 0.010$) between week start (4609 ± 1081w) and week end (5192 ± 605w) peak power values also resulting in a moderate (ES = 0.67) increase in peak power values (See **Figure 5**).

In addition there was also a significant difference ($p = 0.020$) between both training week start PP values.

A Mann-Whitney U test determined differences between pre-match (5122 ± 915w) and post-match (4517 ± 1064w) peak power values following 48hrs of recovery determining a statistically significant difference ($p = 0.004$) but also moderate (ES = 0.61) negative reduction (See **Figure 6**). Although an Independent Samples T-Test showed no statistical difference ($p = 0.733$) between pre-match (5275 ± 792w) and post-match (5202 ± 726w) peak power values following 72hrs of recovery despite a trivial (ES = 0.097) decrement being acknowledged.

The results from the mixed-model design ANOVA indicate a significant reduction ($F_{1,70} = 7.273$, $P = 0.009$) in peak power between the 48hr and 72hr values with an interaction between the recovery durations ($F_{1,70} = 4.462$, $p = 0.038$) therefore identifying that less recovery results in a greater deficit in peak power which is further supported by a significance difference ($F_{1,70} = 4.885$, $p = 0.030$) determined between recovery periods.

5.0 Discussion

In relation to the first hypothesis that the accumulation and magnitude of impact loads would result in greater decrements in PP outputs, none of the resulting data can categorically support this notion. In the instance of the three day training week there were significant, but weak, negative correlations identified for zones 2, 3, and total impacts (See **Figure 1**), between week start and week end PP differences. Zone 5 impacts had a stronger correlation, which corresponds to that of McLellan and Lovell (2012), with correlations to greater magnitudes of impacts and increases of CK, however there is insufficient evidence to suggest throughout all other testing phases to suggest that this is reliable. Within the four day training week there were no significant correlations at all within any of the five zoned impact magnitudes or total instances, with only zone 1 and 4 impacts having a positive correlation. Findings from match play recovery also do not support this particular hypothesis, in that there were non-significant negative correlations between impacts of all zones individually, but also in total, as a result of 48hrs and 72hrs recovery. This is with the exception of zone 5, 72hrs recovery impacts, which had a positive correlations similar to zone 1 and 4 of four day training weeks. The conclusion gathered as to these counter-intuitive positive results is potentially due outliers. Each mark represents peak power difference in relation to the number of impacts within each zone, and in these instances, from a visual perspective there is a greater dispersion of markers, thus increasing the potential for outliers, indeed there are four particular low PP values likely to affect overall week start PP values. These outliers however, cannot, or should not, be ignored as the data is representative of an individual's state of fatigue as a result the training week, which may require intervention from medical or strength and conditioning staff, in terms of further recovery or preparation for competition.

There is however support for the second hypothesis whereby the duration of recovery or training week will allow for a greater return to pre-training or pre-match PP values. Following a three day training week there was a non-significant although trivial change in PP difference (5077 ± 578 vs 5002 ± 579w). This is in contrast to a significant and moderate increase in PP values from a four day training week at week start (4609 ± 1081w) and week end (5192 ± 605w; See **Figure 5**). Similarly, at 48hrs post-match PP (4517 ± 1064w) are significantly less, with a moderate effect, than pre-match values (5122 ± 915w). No significant trivial changes occur between pre- (5275 ± 792w) and post-match (5202 ± 726w; See **Figure 6**) 72hrs PP recovery. The more defining point is that 48hrs post-match values are identified as being significantly less than 72hrs post-match recovery PP values, indicating that extended recovery periods allow for greater recovery and fully supports the hypothesis.

The supportive notion of this study was that extended periods of time allow for greater recovery, which is in support of findings within high intensity activity and workloads that incorporate eccentric loading and impacts (Andersson et al. 2008, Baird et al. 2012, Dousset et al. 2007, Eston, Mickleborough and Baltzopoulos 1995, Nicol and Avela 2006). At 48hrs and 72hrs post-match recovery intervals there was no opportunity for the presence of fatigue to be as a result of metabolite accumulation or substrate depletion, as ATP resynthesis would have occurred; thus unlikely to effect the contractile element of force or power production (Kayser 2003, Shei and Mickleborough 2013). An example of this would be Mclellan, Lovell and Gass (2011) in identifying within rugby league that PF was significantly decreased 30mins post-match, but had returned to baseline values within a 24hrs period. However, other studies have highlighted that PP has not returned to pre-match values for durations beyond 48hrs depending on the intensity of the activity or sport (Cormack, Newton and McGuigan 2008, Hoffman, Nusse and Kang 2003). For this reason, the significant reduction in PP identified in this study is more likely the manifestation of NF through the involuntary reduction of voluntary activation of the muscle, resulting in reduced maximal power production at 48hrs post-match in comparison to 72hrs. This form of reduction has previously been related to altered mechanics of technique – in this case the CMJ, a decrease in stiffness of the knee extensors and also impairment of the SSC (Avela et al. 1999, Toumi et al. 2006). Furthermore, within rugby union the high intensity activity has the tendency to recruit fast twitch muscle fibres with motor units that generate high force. These fibres are affected by reductions of afferent signals to the CNS, due to force producing and transmitting structures being damaged from match orientated activity, alongside impacts and collision loads. Overall this effects the size and number of muscle actions and so neuromuscular function is reduced, which has a direct effect upon PP as its generation is dependent upon all of these facets (Cormie, McCuigan and Newton 2011, Enoka 2008, Gandevia 2001, Komi 2000, Marshall 2005, Newton and Kraemer 1994). Therefore, in the instance of match play recovery between 48hrs and 72hrs, the significant differences between values are to be expected as during the time interval between playing and the post-match CMJ, the players did not perform any form of training thus there was nothing to interfere with recovery and there were no accumulative effects in terms of NF.

From the training perspective the effects of NF are potentially evidenced between the differences of a three and four day training week. However, in this instance the effects of continued exposure to impact loads has to be considered. Previous investigations such as those by Smart et al. (2008), Takarada (2003), and Young, Hepner and Robbins (2012) have all made correlations to impact loads and peak values of CK; a measure utilised in the monitoring of muscle tissue damage. Of importance to this present study is its concomitant relationships with the timeframes of depleted performance measures (Andersson et al. 2008, Howatson and Milak 2009, McLellan, Lovell and Gass 2011). This relationship is to be expected as muscle infrastructural loss, identified through the presence of CK, and NF are inextricably linked which makes the relationship important with regards to the continued exposure and magnitude of impact loads within a training week.

As a result of a three day training week it seems that PP had an insufficient timeframe in which to recover fully, or was at least able to maintain its values as a result of exposure to impact loads generated in comparison to the significant increase within the four day training week. Initially, consideration at this point must be given to the significant difference between week start PP values. Within the dataset of the four day week, four specific outliers were identified. From an applied perspective, these values cannot be ignored as they are as a result of individuals not being able to recover fully from match play. This initiates thought towards the limitation of reviewing data as a group over that of individual positions or players. The outliers could be as a result of certain positions generating more impacts within a game, thus causing greater muscle damage and NF, therefore requiring longer durations of recovery over their counterparts. However, in taking the data as it stands within the four day training week, it cannot be misinterpreted that the additional day was one of recovery, but in fact one of training. Thus the training load upon the player over four days has the potential to be higher. Indeed, it was found that within the four day training week there were significantly more zone 2, 3 and 4 impacts generated (See **Table 4**), which potentially exposes players to greater muscle infrastructural damage and NF (McLellan and Lovell 2012, Smart et al. 2008, Takarada 2003). Yet in this instance the four day training week allowed for a greater return or increase in PP over that of three days. Thus, a key factor in both of these instances is that during a four day training week the training load is tapered, so that the vast proportion of impacts and high intensity workloads should have been generated within semi- or full-contact sessions on the second training day or before (See **Table 2** and **Table 3**). This therefore suggests that there has indeed been greater time for recovery allowing for the increase in PP. Considering findings of Ispirlidis et al. (2008), Mclellan, Lovell and Gass (2011), Smart et al. (2008), and Takarada (2003) if the accumulation of the majority of impacts, which are known to cause muscle tissue damage, had been later in the four day training week a decrease in PP values would have been expected at the week-end stage, although that is not the case. Additionally, the time course of recovery as a result of higher intensity days has relevance. Irrespective of the length of the training week, it was the second training day (See **Table 2** – **Table 4**) that training sessions typically had the greatest planned intensity in respect to collisions. During a three day week this allowed 48hrs of recovery (inclusive of a day off) whereby in a four day training week this would be 72hrs recovery (inclusive of a day off). This reaffirms the findings of recovery limits identified by Komi (2000) and Nicol et al. (1996) in that no significant decrements have been found, it would also be indicative of the recovery durations of this study itself.

5.1 Practical Implications:

Further analysis as to the accumulative effect of impacts and NF and the time course to which players are exposed to stimulus is required. For example based upon this study a 48hrs recovery period prior to entering a three day training week, i.e. a Saturday to Friday turnaround, would suggest greater physical stress and exposure to NF as a result of limited recovery within a short time frame. Similar was identified by Ronglan, Raastad and Børgesen (2006) within international Handball whereby three training days occurred prior to three days of match play. Immediately prior to commencement of competition, as a result of the NF elicited from the training camp, 20m sprint times were already decreased. Therefore if the post-match recovery from a match or intense bout of training is short and the subsequent training week is short but intense before competing again the likelihood of recovery and return to optimal performance is weakened. Likewise, a longer training week, i.e. Friday to Saturday turnaround, should not automatically mean that greater training loads can be tolerated without effecting performance as it would be dependent upon the impacts generated, the time of exposure of impacts and their accumulative load. Having understanding of this is vital as within a competitive season the training week is often dictated by the fixtures themselves. It also cannot be ignored that during a competitive training cycle consideration must be given towards concurrent stimulus or training modalities, such as strength and conditioning alongside skill work and specific rugby sessions, which could also effect a player's return to pre-match performance levels (Cormack et al. 2008a, Marques et al. 2008).

Whereas there were significant negative correlations within the three day training week there was insufficient evidence to determine unconditionally that they had a detrimental effect upon PP or the manifestation of NF. It did however highlight the possibility that the time at which players are exposed to the impact stimulus may have importance. Within collision sports there is the need to develop skill and prepare for competition (Gabbett, Jenkins and Abernethy 2012a, Gabbett, Jenkins and Abernethy 2010), whilst the inclusion of impacts through correct tackle technique will improve a players skill levels thus reducing the risk of injury (Quarrie and Hopkins 2008). Takarada (2003) also indicates that impacts within training might be necessary in order to allow adaption thus reducing infrastructural loss and release of CK, which is similar in regard to muscle structural loss as a result of eccentric loading (Baird et al. 2012, Cormie, McGuigan and Newton 2010, Cormie, McGuigan and Newton 2010). Therefore, there still remains a need to identify the amount of impacts within thresholds a player can tolerate for adaptation and skill development without significant detrimental effects on performance, whilst allowing time for recovery, and timed appropriately to avoid cumulative stress resulting in reduce performance ability through NF (Howatson and Milak 2009, Moreira et al. 2014, Newton et al. 2008).

From an intervention standpoint, grouped data has potentially masked the benefits of both the impact load measure, but also the variation in PP values with regard to NF or recovery. Waldron et al. (2011), in reviewing mechanical and physiological demands of rugby league, clearly states that grouped data as opposed to within-individual data, was a likely reason for weaker relationships identified with their study. This would certainly ring true in this case when reviewing PP difference values. As a group following a three day training week there was a 1.5% negative difference between week start (5077 ± 578w) and week end (5002 ± 579w; See **Figure 5**) PP values, which was shown to be non-significant and a trivial change. Conversely, within the four day training week, week start (4609 ± 1081w) and week end (5192 ± 605w; See **Figure 5**) PP differences result in a 9% significantly different and moderate change. It cannot be determined if the 1.5% difference is in fact detrimental to the entire group, over that of individuals or positions in isolation, likewise, whether a 9% increase equates to a significant increase in performance over the squad. The roles within rugby union have been defined within this study to be different amongst positions, as an example, the findings of Deutsch, Kearney and Rehrer (2007) identifying 66.9 ± 15.8 static events for the forwards in comparison to 9.5 ± 5.7 for the backs, and 80 ± 17 and 21 ± 11 by Duthie, Pyne and Hooper (2005) clearly prove this. The backs are not involved in scrummaging, but they are involved in greater velocity efforts, or are likely to go into contact at higher velocity, therefore are exposed to impact and mechanical stresses in a different format as to the forwards. Therefore, finite reviews and comparison of data in order to allow more effective reaction to datasets are required. One such method used within this particular environment is that of the z-score. This simple method from an applied perspective, as used by Duthie (2006), Hopkins (2004), and McLean et al. (2010), helps remove fluctuations or individual patterns of a measure, thus representing a value in terms of the number of standard deviations above or below the mean. This has been used with success in terms of PP whereby a decrease of 1 z-score ordinarily results in communication with strength and conditioners and medical staff to instigate further attention to soft tissue therapy, or release through foam rolling to enhance recovery or ability to cope with further training on that particular training day (Healey et al. 2014, Hilbert, Sforzo and Swensen 2003, Pearcey et al. 2015). A decrease of 2 z-scores invokes a more robust intervention requiring time off feet or limitations to sessions. Therefore it is conceivable that if impact and PP difference data in terms of training and match recovery were broken down to positions, stronger relationships could potentially be identified, henceforth, providing a relationship could be found, a z-score for impacts could also be linked to NF and improve the speed of reaction to datasets to enhance any recovery or return to peak performance.

5.2 Further Research:

All of these aspects discussed identify a number of key factors to be considered for future investigation. In order to acquire more accurate data with regard to post-match recovery, prior to entering a training week of three or four days, an investigation needs to be over a longer duration. The majority of research reviewed have tended to be short duration competitions, or as a result of single matches (Ispirlidis et al. 2008, McLellan and Lovell 2012, Ronglan, Raastad and Børgesen 2006, Smart et al. 2008, Takarada 2003). The review of Cormack et al. (2008a) over an entire season was the only one of its kind reviewed. In this instance they were able to refine their findings from their previous research (Cormack, Newton and McGuigan 2008), and develop it further in order to increase its application to Australian Rules football. In relation to impact loads, this study was the first of its kind within professional rugby union, therefore there is benefit in more longitudinal studies and could identify more relevant correlations within different phases of a competitive season. This would also provide increased clarity with relation to the recovery period prior to a three or four day training week in terms of NF. At present, for example, it is not known as to whether between PP values at the beginning of the four day training week were as a result of only 48hrs recovery, which this study has shown to be ineffective in allowing recovery, or 72hrs, which improved the likelihood of reduced or depressed indication of NF through increased PP. This would have particular relevance in relation to the season within rugby union being dictated by the matches themselves. Knowing how to manipulate training stimulus in light of recovery levels, to avoid exacerbating fatigue and allowing a quicker return to a more recovered state for repeat performance over prolonged periods of time, is clearly advantageous. And that in-part remains a reason for this study. Being able to differentiate when a player is fatigued, or not, as a result of the demands of rugby union in relation to impacts offers opportunity to achieve optimal states for performance through structured recovery and prescription of training stimulus.

As mentioned, another aspect relates to utilising data by positional groups as opposed to the group as a whole. West et al. (2014), Twist et al. (2012), and Young, Hepner and Robbins (2012) all suggest the use of profiling whereby relationships and correlations are identified for them specifically. Ronglan, Raastad and Børgesen (2006) discuss the recovery from NF amongst players in differing positions within handball, whilst McLellan and Lovell (2012), break down their analysis to individual playing groups and are indeed able to identify relationships within rugby league of impacts to NF with some success, yet nothing has been investigated in rugby union. Within rugby union there are a number of positional groups, whilst the players within those positions are particularly non-homogenous from a physical perspective but also by definition of the roles they play during a match or training (Duffield et al. 2012, Duthie, Pyne and Hooper 2003). This is one area that has begun to benefit from the use of GPS with much detail already known with regard to the more locomotor aspects (Cahill et al. 2013, Coughlan et al. 2011, Cunniffe et al. 2009), but further possibilities exist towards the magnitudes of loads from an impact perspective and multi-planar mechanical loading (Aughey 2011, Boyd, Ball and Aughey 2011, Young, Hepner and Robbins 2012). An example could be between a scrum-half and a fullback, both are backs, yet with very different roles. On average a scrum half covers greater distances but has slower maximal velocities in comparison (Cahill et al. 2013, Quarrie et al. 2013). From an impacts point of view, the scrum half may generate greater lower magnitude impacts from the work within rucks or mauls, yet the fullback may generate less impacts but the magnitude of the impact may be greater because of the velocity component as a result of running into contact. Yet so far it has not been identified as to whether or not the greater accumulation within a particular zone or the greater magnitude bears the most significance. Hence, positional variation for future research as opposed to group analysis is vital, therefore it should be considered that utilising group data as a whole has potentially masked the identification of relationships between zoned impacts and NF.

There is a restricting factor with relation to grading and registering impacts which, in part, is due to the method of measure itself. It has become clear that impacts or collision are non-linear and chaotic in nature, the outcome of which may not be detected by one measure alone. This potentially is shown by the total impact events within **table 4,** which details impact events within this study from the matches recorded by Catapults tackle load measure, ranging between 42.2 ± 26.9 and 49.5 ± 29.8 per game. These are not comparable to other research when you might consider that Lacome et al. (2014) identifies 53 static events alone occurring within French international games, or 89 ± 21 and 24 ± 10 events within English elite rugby union by Roberts et al. (2008). It is not suggested that the particular measure utilised is inappropriate, yet combinations other measures, such as playing load, employed by Young, Hepner and Robbins (2012), could have more advantages in measuring the combined multiplanar forces upon a player from accelerometry, and could assist in the monitoring of forwards more specifically for close quarter work, as it omits the requirement of any precursory activity prior to the impact. The understanding of the magnitude of impact events and the aggregate effect is also a limitation. Thus far, McLellan and Lovell (2012), within rugby league, and Coughlan et al. (2011), within rugby union, have produced research relating to the impact through the use of Team AMS; GPSports GPS units, and values of g-forces. These findings are supportive of the findings within this study of zone 5 impacts within the three day training week and it would be anticipated that a greater impact would result in greater muscle damage. However, contextualising an impact event of for example greater than 10g by McLellan and Lovell (2012) is difficult, despite correlations in this case to increased CK markers indicating muscle damage, as there is no point of reference for comparison, and the effect upon the individual will vary according anthropometric characteristics (Duffield et al. 2012, Quarrie et al. 2013, Smart et al. 2008, Takarada 2003). Similarly, within this study, the proprietary algorithm also prevents comparison to equivalent tackle events, but also aggregation, or weighting of combined impact events. For instance, it cannot be determined as to whether multiple zone two impacts, which might be generated from a scrum half, is the equivalent of one zone five impact generated by a prop in one single tackle. Likewise, the aggregation resulting in the total number of impacts, is flawed as it does not allow a true indication of the combined effect or magnitude of the multiple zones. Thus an understanding within an applied environment of this concept would benefit and enhance support staffs ability to react to impact loads in terms of training and recovery regimes.

In addition there is the omission of the impact loads from scrummaging. It is noted that it is not just the impact from the engagement that are likely to cause muscle structural damage but the subsequent pushing forces upon the body that are likely to cause fatigue as suggested by Morel et al. (2015). Physical characteristics, experience and technique have bearing on the impacts and forces generated within the scrum, not just of the individual but the opponent (Cazzola et al. 2015, Cazzola et al. 2015, Milburn 1990, Preatoni et al. 2015, Trewartha et al. 2015). Yet the forces will vary amongst the positions within the scrum, whereby the front row forwards are exposed to the highest magnitude of the impact and pushing forces, then second row, with the back row producing the least forces of all, but that is not to say these forces are not still high (Milburn 1990). This has been considered to be beyond the remit or scope of this study, and it is not likely that GPS accelerometry will be able to detect the forces or impacts within a scrum for some time (Lawrence 2015). It does have relevance however when considering the exposure of impacts and mechanical loads as a whole, and once more encourages the use of positional data as opposed to group data research.

5.3 Conclusion:

The monitoring of impact loads from both three and four day training weeks and match play within rugby union has not provided conclusive evidence that the exposure to, or the accumulation of, impact loads result in increased levels of NF through the measure of PP. This could potentially be as a result of grouped data masking the actual results, therefore, a more granular, positional perspective may be required as to the specific workloads and work rates resulting in the generation of impacts throughout specific zones within both training and match play. Conversely it has been identified, predominantly through match play, that the duration of recovery has a significant effect on NF, whereby less recovery results in a greater deficit of PP values, therefore increased NF. Although the extended training week identified an improvement in PP this is in the presence of increased exposure to impacts. Therefore, from the aspect of training recovery for a return to peak performance prior to competition, there is a need for deeper analysis over extended periods of time into the time course of exposure to impact during the training week, whereby the number of impacts and their magnitude are recorded and related to the amount of recovery available prior to playing. Similarly, durations of post-match recovery requires long-term investigation with regard to returning to a training week whilst still presenting signs of NF through reduced PP, consequently putting the player at risk in terms of injury, but also limiting their ability to perform or train fully. Furthermore, investigation into the aggregation of impact loads and mechanisms of grading their magnitude is of importance. This in tandem with the development or combination of techniques towards effectively recording events such as scrummaging, rucking and mauling alongside tackle events, in order to more comprehensively measure impact or mechanical loads that players are exposed to, thus providing support staff with the capability of reacting more efficiently to training stimulus and the preparation of players for competition throughout a season.

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